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Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force

G.A. Clark and I.A. Burch

DSTO-GD-0288

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ABSTRACT

Emergent technologies are the technologies that may impact on future Naval ship design and construction. The driving factor in ship design in this century will be the capability requirements and as these change, emergent technologies will be needed to meet these new requirements. These technologies will define areas such as construction methods, propulsion systems, construction materials, signature management, survivability, self-protection, command and control and among other aspects, the legal obligations associated with operating ships on blue water or in port.

This report describes the technologies that will drive ship design for the next generation of the Royal Australian Navy's Afloat Support Force (ASF) where afloat support can be categorised under the following tasks:-.

- replenishment-at-sea;
- sea transport;
- amphibious operations, and
- logistics over the shore.

The requirements of an afloat support force are specific because of the operations they perform. These requirements encompass military lift capacity, loading and unloading needs, range, endurance, replenishment needs and environmental considerations. New technologies will lift the capabilities of the next generation of ASF vessels by making them faster, more efficient and less vulnerable. Improvements in capability will also translate to broader operational requirements of the afloat support vessels resulting in a more effective force.

RELEASE LIMITATION

Approved for public release

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE & TECHNOLOGY ORGANISATION
DSTO

Published by

DSTO Aeronautical and Maritime Research Laboratory
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

Telephone: (03) 9626 7000
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AR-011-881
May 2001

APPROVED FOR PUBLIC RELEASE

Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force

Executive Summary

Emergent technologies describe the technologies that may impact on future ship design and construction. The driving factors for future vessel design will depend on the capability requirements, the funds available and the technologies available. These technologies will define areas such as construction methods, propulsion systems, construction materials, signature management, survivability, self-protection, command and control and among other aspects, the legal obligations associated with operating ships on blue water or in port.

This report describes the technologies that will drive ship design of the next generation of the Royal Australian Navy's Afloat Support Force, where afloat support can be categorised under the following tasks:

- replenishment-at-sea,
- sea transport,
- amphibious operations and
- logistics over the shore.

Replenishment-at-sea is the underway replenishment of fuels and water to naval combatants and support forces and is undertaken by ships with large fuel capacities and long range and endurance.

Sea transport describes the transport of personnel or equipment by sea for strategic, operational or administrative reasons. The defence of Australia may require sea transport to parts of the Australian coastline inaccessible by road or air, in particular the northern coastline and especially during the wet season.

Amphibious operations are an important component of sea transport and become necessary where port facilities for loading and unloading cargo are limited or not available. Again this applies particularly to the northern coastline. Amphibious operations are performed by a combination of large and small platforms, the larger platforms transporting cargo and/or personnel to the required region and the smaller platforms undertaking the ship to shore transfer.

The capability requirements of afloat support force (ASF) vessels will define areas such as military lift capacity, loading and unloading needs, range, endurance and replenishment needs but the new technologies will determine how the capabilities are achieved. As the capability requirements increase, newer technologies will be incorporated that allow those requirements to be fulfilled. Another aspect that will

drive ship design is emission control, the lowering of allowable pollutant levels due to increasingly restrictive environmental laws and requirements. The pollution limits will cover exhaust gas emissions, sewerage, garbage and oil discharges.

Some of the technologies described in this report are generic and applicable to general naval ship production.

Contents

1. Introduction

Emergent technologies describe the technologies that will impact on ship design and construction. The driving factors for future vessel design will depend on the capability requirements, the technologies available to meet those requirements and the costs associated with developing and incorporating these technologies. These technologies will define construction methods, propulsion systems, materials, signature management, survivability, self-protection and command and control. New or ongoing technology developments will also be important in being able to meet the expected increase in emission requirements associated with operating ships in blue water or berthed in port.

This report describes the technologies being developed or conceived today that will drive aspects of ship design of the next generation of the Royal Australian Navy's (RAN) Afloat Support Force (ASF), where afloat support can be categorised under the following tasks:

- replenishment-at-sea;
- sea transport;
- amphibious operations, and
- logistics over the shore.

Replenishment-at-sea is the underway replenishment of fuels and water to naval combatants and support forces. The ships that serve this function may also provide limited stores support. Replenishment-at-sea is undertaken by ships with large fuel capacities and long range and endurance.

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The capability requirements of ASF vessels will define areas such as military lift capacity, loading and unloading needs, range, endurance and replenishment needs, but new technologies will determine how the capabilities will be achieved. As the capability requirements increase, newer technologies will be incorporated that allow those requirements to be fulfilled. Another aspect that will drive ship design is emission control, the lowering of allowable pollutant levels due to changing environmental laws and requirements. The pollution limits will cover exhaust gas

emissions, sewerage, garbage and oil discharges. Meeting exhaust gas emission requirements could have a considerable effect on the types of fuel and therefore the types of propulsion system that could be used.

Although the descriptions of ship design technologies in this report relate to afloat support vessels, many can be considered generic and applicable to most naval vessels. Afloat support also comprises logistics over the shore or the transfer of equipment or personnel from ship over the shore and this function is not limited to water craft. Helicopters or vertical take-off aircraft can also fill this role and developments in this technology cannot be ignored.

2. Logistics over the Shore

Logistics over the shore covers the transfer of materiel and personnel and the transportation to and from a vessel to shore.

2.1 Loading Facilities and Requirements

2.1.1 Crane Technology

The current technical status of cranes for materiel transfer at sea will change as advances in servo-control and automation are introduced. At sea, the use of cranes is severely limited by the sea state and wind loads. Emerging technologies that will widen the window of operation in higher sea states include:

- automated anti-pendulum support [1];
- stabilised shipboard crane[1] for unloading in heavy seas [2] shown in Figure 1;

[1] This technology was studied in 1987 and found then to be economically and technically possible.

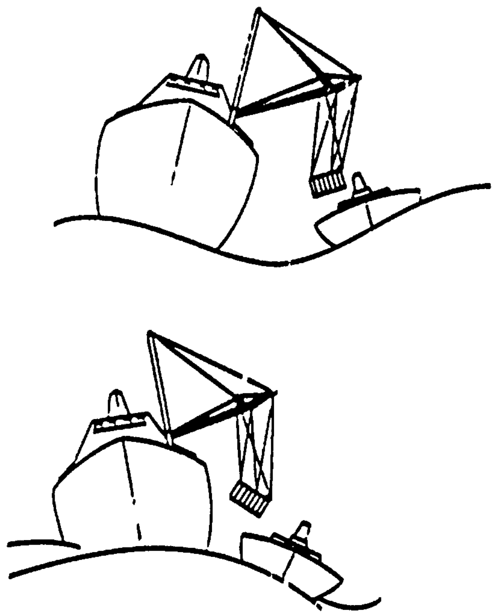

Figure 1 Stabilised shipboard crane operation [2]

- electronic crane control to lift loads at peak of heave motion and when the lifting line is taut [3];
- automated loading using hydraulically driven articulated arms [4];
- fibre composite structures decreasing weight, radar signature and maintenance;
- computer guided articulated arms that are targeted, the end of the articulated arm will move smoothly with respect to a target irrespective of the motion of the system's base [5].

2.1.2 Well Dock

Modern amphibious ships incorporate a floodable well dock in their design to carry watercraft and assist unloading. This design frees deck space normally allocated to the transport of watercraft and allows the watercraft to be launched directly from the well dock rather than over the side of a ship. The dock also creates a protected area inside the ship reducing the effect of wave action on the watercraft compared to the unprotected conditions with over-the-side transfers or ramp marriages.

2.1.3 Mobile Pier

A rapidly deployed mobile pier (Figure 2) is being examined by the USN [6]. The pier would be towed or self-propelled to a harbour where it would establish itself as a pile supported roadway to the shore. The pier would fix itself to the sea bottom by the means of retractable piles and possess its own cranes for rapid discharge of cargo and a ramp for RO-RO vessels.

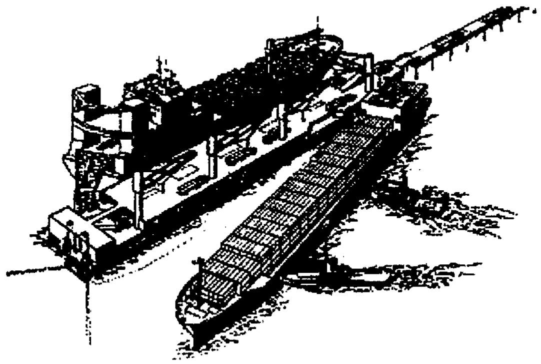

Figure 2 Rapidly deployed mobile pier [6]

2.1.4 Causeway Systems

Floating causeways are another means of unloading vessels although current systems are limited to less than sea state 3. The USN is investigating an advanced causeway system that will be sea state 3 rated [6]. The system will be modular and basic prototypes have been trialed. As well as being capable of ferrying cargo and vehicles to shore, it is intended to be compatible with hovercraft (air cushion vehicles) for joint logistics over the shore (JLOTS) operations (Figure 3).

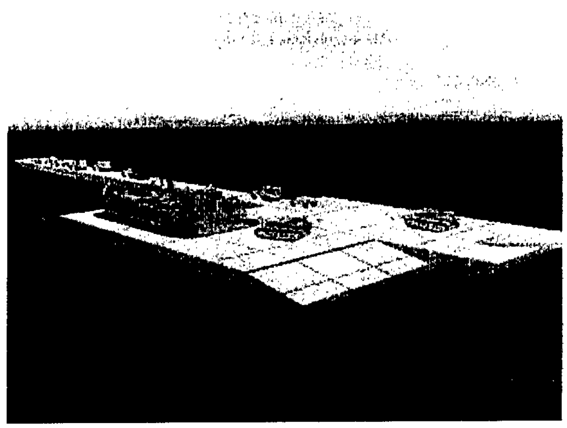

Figure 3. Sea state 3 capable causeway [6]

2.1.5 Ramp Marriage

Unloading or loading at sea by ramp marriage is a common event but the capability is controlled by wind and sea state. The process involves skill and requires time to achieve a successful marriage between an amphibious vessel and landing craft. Technologies that could be developed to hasten and maintain safety during a marriage include:

- automated articulated arms to grab and hold a landing craft. The arms are targeted by sensors onto appropriate couplings on the landing craft, irrespective of the vessel's motions;
- developments in automated mooring systems [7] that automatically align and guide the landing craft with the ramp;
- dynamic positioning to maintain station irrespective of the wind and sea state.

These technologies will be aided by the continuing miniaturisation of global positioning systems (GPS) married with compact and robust computer technology running servo control smart software incorporating artificial neural networks and fuzzy logic.

2.1.6 Sea Wall

Research is currently underway into calming the sea around a vessel to enable loading and unloading in sea states 3 and higher. This technology has been listed as an important technology to develop in the USN Science and Technology Requirements Guidance report [8]. This technology would increase the window of opportunity for JLOTS and amphibious operations. One such development in this field is the Rapidly Installed Breakwater System (RIBS) [6], (Figure 4). A system to rapidly deploy a breakwater *'to significantly reduce the seas around a JLOTS operation to below sea state 3'*. This technology would enable existing sea state 2 equipment to operate in higher sea states.

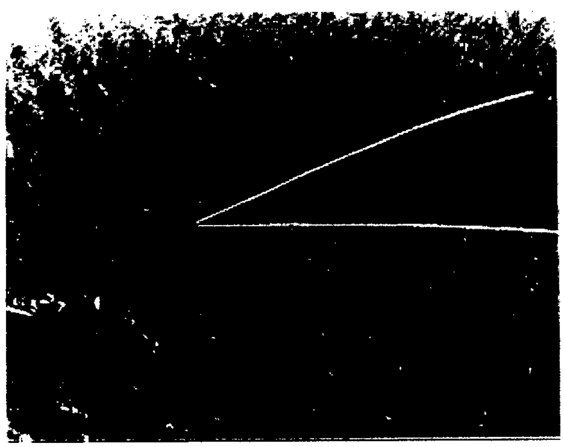

Figure 4. Rapidly installed breakwater system [6]

2.1.7 Sea Cargo Organisation

Cargo organisation within a vessel (particularly amphibious vessels and sealift ships) is usually handled by scaled cardboard cut-outs and scaled drawings of the vessel. Smart software decision aids could advise on the type of equipment for the type of operation, determine loading arrangement within the vessel together with commensurate

manifests. All loads could be electronically tagged and remotely read enabling real-time confirmation of loading and unloading state and estimated time to completion.

2.1.8 Secure Lashing of Loads

Chains and turnbuckles are currently used to secure loads aboard vessels. These are bulky, heavy to manhandle and are subject to corrosion. Web lashings have been introduced that are manufactured from polyester offering ease in handling and operation and designed to exceed International Maritime Organisation (IMO) requirements [9].

2.2 Amphibious Vehicles

The development of high speed amphibious vehicles will reduce ship to shore transit time where a reduction in transit time reduces the risk of a strike from shore based weapons.

2.2.1 Amphibious Assault Vehicles

A high speed advanced amphibious assault vehicle (AAAV) is under development by General Dynamics Land Systems. These vehicles will have a significant speed advantage (20 kts) over the 7 kts speed of the current US assault amphibian (AAV7A1) and can operate at full speed in sea state 2. The superior speed of these vehicles is achieved by water-jet propulsion and planing hull technology.

2.2.2 Air Cushioned Vehicles

Landing craft air cushioned (LCAC) vehicles can be used for low cargo capacity, short range but high speed lodgement over the shore. LCAC's have a real amphibious capability, being able to operate over land and water at high speeds. Their amphibious nature could be utilised where shallow beaches and tidal variations reduce the effectiveness of conventional landing craft.

High life cycle costs currently associated with the air cushion skirt and high fuel consumption (gas turbine powered) reduce the attractiveness of LCACs. Air cushioned vehicles are limited to sea states equivalent to the skirt height. Problems are also associated with fan draughts and their effect on personnel working in close proximity. LCACs have a limited range and would need to be carried on or within the main platform.

2.2.3 Small Craft

2.2.3.1 Jet Skis

Although not part of the Australian defence inventory, jet skis may play a role in the future. This form of sea transport has many features that could be adapted for operations such as transporting personnel or equipment rapidly to and from shore. Features of high performance commercial equipment are detailed in Table 1. Recent

developments in the designs have seen the ability to quickly attach an outer body [10], converting the ski into a water jet powered shuttle craft allowing an extra 3-5 passengers (Figure 5).

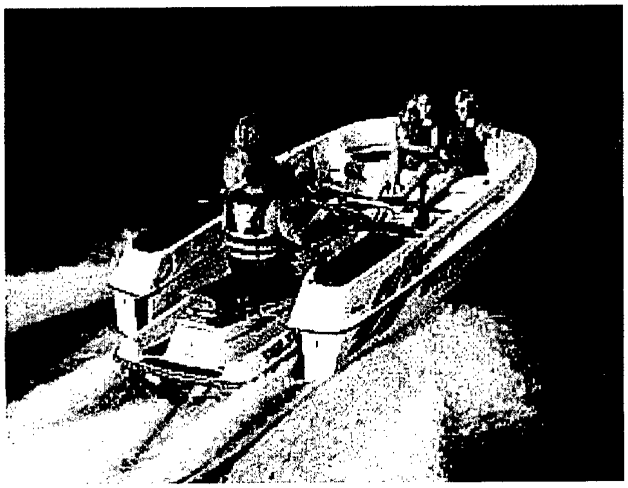

Figure 5. Shuttle craft attachment on a jet ski [10]

Table 1 Current and potential features of Jet Skis [10]

Properties	**Current commercial features**	**Features useful to Afloat Support.**
Speed	88-93 kph (50-58 mph)	High speed transport between shore and vessel. Relatively quiet with muffling of exhaust
Draught	Can operate in 25 cm of water	Useful in high tidal areas
Seaworthiness	Will safely operate in 3 m surf	Greater than sea state 4 operation
Construction	Fully moulded polymer hull, built in buoyancy, all aluminium engines with anti corrosion coating.	Very tough, potential for very low magnetic signature and low radar cross section.
Propulsion	>350 kg thrust by shielded water jet (Engine:120 hp)	Operation in shallow waters and lower noise than external propeller propulsion.
Accommodation	1-3	Attachment will allow an extra four people to be transported. Could be adapted to carry equipment if required.
Mass	~250 kg	Light weight for easy deployment at sea.

2.3 Air Transport

Improvements in payload, speed and range will see an increasing reliance on vertical take-off and landing (VTOL), short take off and landing (STOL) and short take-off and vertical landing (STOVL) craft for logistics over the shore.

2.3.1 Helicopters

Helicopters will be indispensable for JLOTS or any manoeuvre from the sea. Future helicopters will utilise more fibre composite and smart material technologies to lower weight and simplify mechanics. They will also need to be fully marinised for the sea environment and capable of being stored efficiently, e.g. folding blades or body.

One development in helicopter technology is the CarterCopter project [11], which aims to produce a high speed autogyro copter, Figure 6, that can take off and land vertically but fly at speeds greater than 480 kph. Such a system may provide many advantages due to its high speed and simplicity.

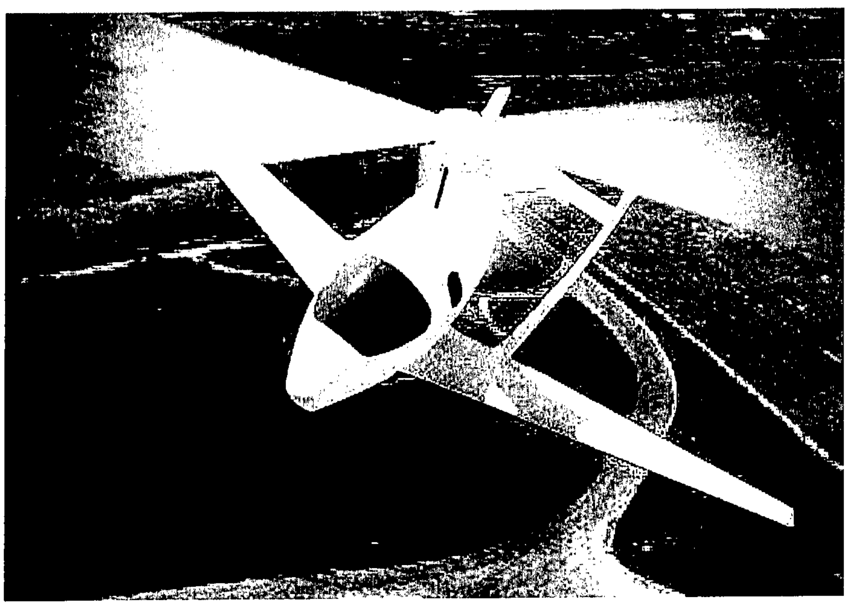

Figure 6. The CarterCopter [11]

2.3.2 Vertical Take-off and Landing Craft

Rotary wing air transport for ship to shore movement has the advantage of short transfer times compared to water craft but may be limited by payload and range. Developments in helicopter technology have resulted in the Bell V-22 Osprey tilt rotor (Figure 7). The Osprey has increased speed, range and payload compared with conventional helicopter technology.

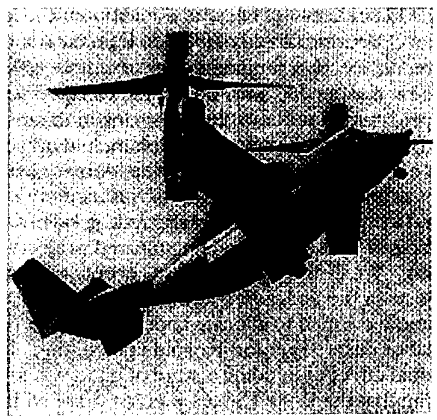

Figure 7. The Bell V-22 Osprey [12]

Comparisons between the Osprey and the Sikorsky UH-60A Black Hawk currently in service with the ADF are given in Table 2.

Table 2. Characteristics of the Black Hawk and V-22 Osprey

	Sikorsky UH-60A Black Hawk	**V-22 Osprey tilt Rotor**
Troop lift	11	24
Max. internal payload	1200 kg	9000 kg
Cargo hook capacity	3600 kg	6800 kg
Max cruising speed	139 kts	314 kts
Range (Vertical Take-off)	319 nm (max Take-off weight)	1200 nm (5443 kg payload)
Range (Short Take-off)		1800 nm (9000 kg payload)

A disadvantage of the V-22 is the relative small dimensions of the cargo bay (1.72 m wide * 1.5 m high) and the steep ramp (18.5 degrees). These two factors may limit the type of vehicles that can be loaded [13].

2.3.3 Aerial Truck

In the report *Technology for the United States Navy and Marine Corps, 2000-2030* [14], a need for a utilitarian subsonic aerial truck has been discussed. This vehicle would incorporate modular technology that is changed according to the mission (e.g. attack or support) and have a low airspeed using simplified propulsion systems. The aerial truck would be STOL or VTOL making it suitable for shipboard applications.

2.3.3.1 Autonomous Aerial Truck

An extension of the aerial truck concept is the autonomous robotic aerial truck. A VTOL vehicle that would be able to carry supplies to troops ashore using GPS guidance all under computer control. The size of a jeep, the vehicle would be sub-sonic and stealthy, delivering supplies when and where they are needed directly from afloat support vessels.

2.3.4 Float or Amphibious Plane

The US Naval Undersea Warfare Center has proposed the addition of floats to a C-130 Hercules aircraft (Figure 8) [15]. These floats would allow the aircraft to put down on either water or land[2]. The craft would have a 12.2 tonnes (27,000 pound) cargo carrying capability. A 2,000 nm range would be possible with 4.5 tonnes (10,000 pounds) of cargo. The draught of the floats would be between 1.5 to 1.8 m (5-6 ft).

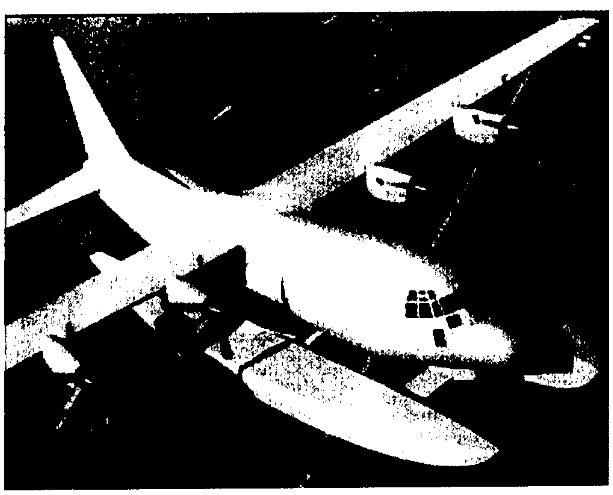

Figure 8. C-130 floatplane [15]

[2] Landing on dirt strips would not be possible with floats.

2.3.5 WIGE Craft

Wing-in-Ground-Effect (WIGE) vehicles (also known as Ekranoplans) combine some of the characteristics of ships with those of aircraft [16]. Using an aerodynamic ground effect they achieve a high lift to drag ratio, operating close to the surface at high speed (Figure 9).

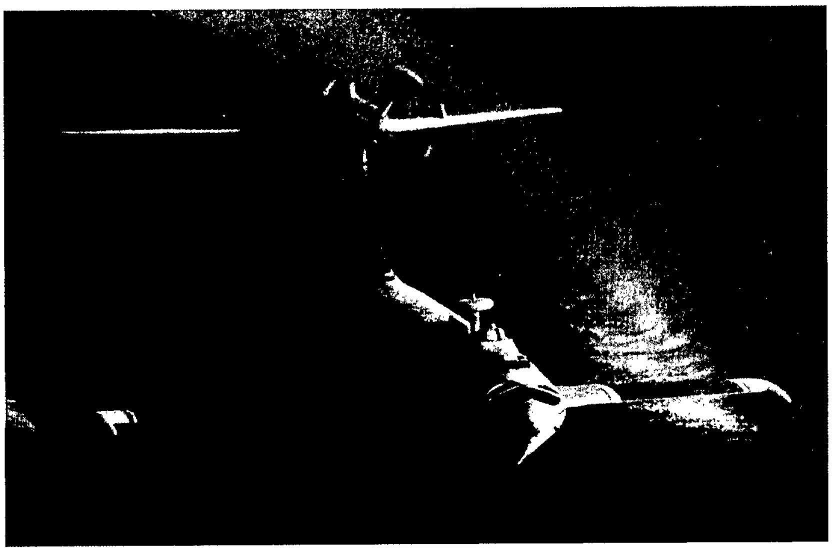

Figure 9. Russian A.90.150 Ekranoplan (WIGE) [16]

Some WIGE designs have achieved cruising speeds of up to 500 kph with ranges in excess of 1000 km. The range and speed of WIGEs make them attractive for amphibious operations.

The distance from the surface that WIGEs operate depends on the wing configuration that produces the ground effect. Consequently, the height of the ground effect region determines the maximum sea state in which the WIGE can operate. Larger vehicles typically operate in higher sea states.

WIGEs will usually take off and land at sea and this aspect of their operation will be sea state limited. However, they will be able to operate in sea state conditions greater than those in which they can take off or land.

2.3.6 Jet Packs and Flying Platforms

Although this technology may seem to be reminiscent of 'Hollywood' movies, the basic technology for jet packs has been available for over thirty years [17]. Originally rocket powered (see Figure 10), modern versions use a miniature jet engine similar to that in

cruise missiles[3]. Such a jet belt or jet pack would have approximately 30 minutes of flight time, c.f. 23 seconds for the original rocket, and allow quick dispersed insertions into or beyond beach heads. The ability to stay low, travel fast and survey wide areas has tactical advantages. The technology could be further developed with modern propulsion system design and materials.

Figure 10. The original rocket belt [17]

A recent development in flying platforms is the Hummingbird, being developed in Israel [19]. Like the US flying platform demonstrator developed in the 1980s [20], it is designed to be flown by a person with little or no experience. The Israeli platform incorporates modern technology for stability and reliability. Weighing 115 kg, it is able to carry a man for 45 minutes on 20 litres of fuel.

3. Signature Management

Signature management comprises technologies that make ships difficult to detect, track and target. A vessel has several signatures, however lowering one may raise another, therefore a systematic approach to signature management is needed where threats and capabilities are balanced in order to obtain the optimum solution.

Landing craft are relatively vulnerable and stealth may prove to be important for their survivability. It is projected that smart weapon technology for land use could be extended to coastline defence, in particular, aerial bombs or missiles that deploy multiple active (or passive) independently targeted submunitions. These submunitions use millimetre wave, infra red (IR), noise sensors or a combination of all to seek out targets[4].

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[3] Bell aerospace developed a jet belt in 1970 and licensed it to Williams International. However, development of Williams "small lift devices" was halted when the Williams jet engine, then the smallest of its kind in the world, was used exclusively in cruise missiles [18].

[4] Northrop Grumman's anti-armour submunition (BAT) uses acoustic and IR sensors to find and attack armoured vehicles. 13 BAT submunitions fit inside a US army tactical missile [21].

3.1 Radar

There are two aspects associated with radar signature. One is to minimise the return radar signal, the other is to minimise detection of radar emissions.

3.1.1 Radar Systems

During operations, naval vessels will typically turn off radar surveillance systems to remain covert. However, a technology known as low probability of intercept (LPI) radar enables vessels and other platforms to maintain radar surveillance. The signal emitted is a frequency modulated continuous wave (FMCW) low power signal that is able to detect craft before their electronic monitoring system (EMS) is able to detect the surveillance radar. This technology is currently available but its advantage may disappear if and when more sophisticated detection systems are developed.

3.1.2 Radar Absorbing Coatings

Radar absorbing coatings include thin paint films, doped rubber tiles and fibre composite materials with the outer plies loaded with radar absorbing material. Radar absorbing fibre composites will continue as the use of fibre composites increase for superstructures and other ship components but thin films will be efficient, cheaper and easier to adapt to older non-stealthy vessels.

A potential radar absorbing method is the doping of sea water with radar absorbing additives and enveloping the vessel in a spray of the doped sea water.

3.1.3 Shape

The British Sea Wraith, Figure 11, incorporates many features of stealth technology. For a low radar cross section, the topside deck is sleek with angled sides while equipment with sharp projections are below deck and/or covered by streamlined cowlings. The design also incorporates radar absorbing or deflecting panels on the superstructure and masts to minimise the radar cross section [22]. When not in use the mast can be lowered, further reducing the radar signature. The shape and positioning of the vessel's superstructure and masts create some confusion within the radar system of an attacking missile causing it to deflect off its intended path [23].

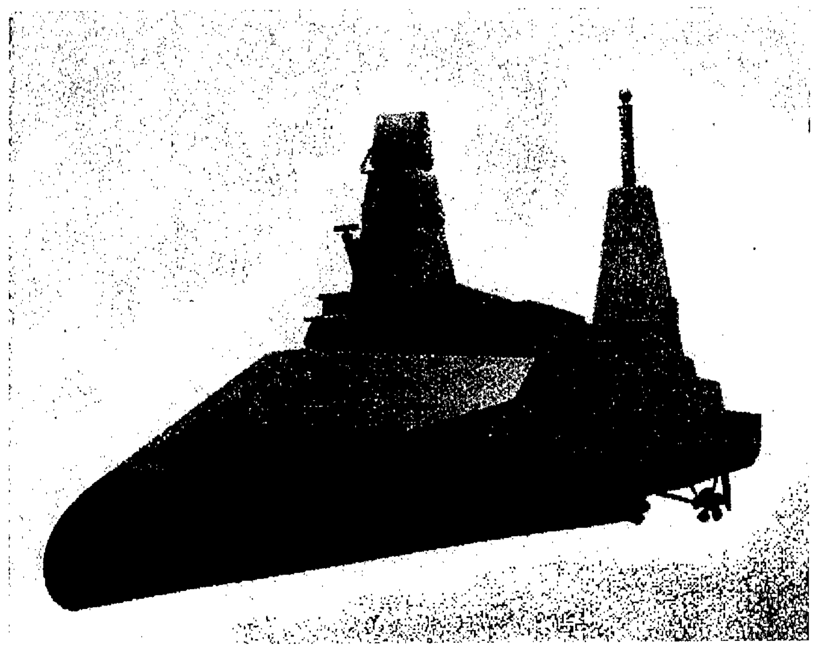

Figure 11. The proposed Sea Wraith [23]

The Swedish experimental stealth craft, the Smyge [16] has demonstrated other shape design features to reduce the radar signature. These include:

- pop-up weapon systems that are normally kept below deck under radar absorbing panels;
- radar absorbing grates/nets over air inlets and exhaust ports.

3.2 Infra Red

Infra red (IR) signatures will be managed in a number of ways:

- more efficient power sources and systems with lower waste heat output (e.g. fuel cells);
- cooling of exhaust gases by sea water spray prior to release into the atmosphere. Blohm and Voss have presented a frigate design with an IR signature reduced by 75% compared with that of a conventional vessel. The cooled exhaust fumes are vented above the water line at the stern at a temperature between 60-80°C allowing the stack to be removed from the vessel [24];
- insulation to reduce IR signals being emitted in certain orientations;
- IR reflecting paint to reduce high heat flux from the tropical sun. The reduction in heat build-up will also lower air-conditioning and overall power requirements;

- introduction of combined heat and power systems where waste heat from power sources will be used for air-conditioning, hot water and steam generation before being released;
- the development of Peltier effect devices to use waste heat from power systems used for the generation of direct current electrical energy [25];
- fine water spray encompassing a ship [22] to mask the IR signature when needed to be reduced to a low level, e.g. when under attack, although this technique can affect the performance of the ships sensors. Future developments may see the addition of components to the water spray to enhance the IR signature reduction.

3.3 Visible Camouflage Coatings

Visible camouflage may be passive or active.

3.3.1 Passive Camouflage Coatings

The traditional approach to camouflage encompasses painting or covering the vessel to match the colour and characteristics of its environment and remove glints. This technique is very effective in haze or fog [26].

3.3.2 Active Visible Camouflage

Active camouflage is defined as camouflage that can change with time and conditions. Existing techniques include light sources to illuminate the vessel to match the background illuminance. This could make a vessel silhouetted on the horizon disappear to the distant visible observer and this could operate with the traditional passive coating on the vessel.

The ability to change a vessel's colour at will could be advantageous when sea colour or other conditions change or when operating close to shore. In some atmospheric conditions covering a vessel with a fine water mist can hide the vessel from visual detection [23].

3.4 Bioluminescence

Bioluminescence is *"the emission of visible light by living organisms"* [27]. Certain marine organisms emit light with the passage of a ship. This display of light can remain visible for significant periods of time leaving a night time trail that can be observed from aircraft and satellites. Even submerged submarines can leave tell-tale trails due to bioluminescence [28].

The source of the light can be from crustaceans (prawns), fish and micro-algae such as phytoplankton. In the warm tropical waters about Northern Australia and South East Asia these light sources are prevalent. In particular, the phytoplankton, dinoflagellates, is well known for producing bioluminescent trails behind passing vessels. This algae

produces a brief, bright flash of light when disturbed by an irritant, e.g. changes in chemical composition, pressure pulses, ultrasound and laser stimulation [28].

The mechanism for the generation of the bioluminescence in dinoflagellates is an internal reaction that is pH dependent [29]. This raises the possibility that a vessel wishing to minimise bioluminescence could inject a chemical into the water to stop the bioluminescent reaction.

Alternatively, maps and periods of likely bioluminescent activity could be produced enabling ships and submarines to avoid bioluminescent activity. Such maps may be produced by aerial scanning of the seas with a laser [28].

Another potential option is the laying of false trails, i.e. a vessel could release an autonomous device that would stimulate the bioluminescence and duplicate the acoustic signature of the vessel.

3.5 Wake

All vessels produce a wake from their passage. This wake is a product of the various drags associated with a body moving through a fluid where turbulence is produced as the boundary layer flow separates from the body. Combined with the turbulent flow from the rotation and cavitation of a propeller, a vessel leaves a spatially expanding and diminishing wake behind it that can be observed by aircraft and satellites. This wake also has a bubble density profile within the water that enables wake homing torpedoes to track a vessel.

Some methods being considered to minimise wake formation include:

- puller propulsion technology using electric powered propeller pods positioned near the bow of the vessel. Turbulent flow from the propulsors is reduced as the flow passes along the vessel [30];
- ship hull design to provide optimum flow across the surface thereby minimising wake and turbulence [31];
- contra rotating propellers [32].

3.6 Electric field

Electric fields are perturbed or produced by a ship in the following ways:

- cutting the earth's magnetic field;
- disturbing the natural electric field that exists between the sea and the atmosphere;
- electrochemical (corrosion) processes within and between the hull, propeller and shaft and the sea.

Methods to reduce the electric field signature include:

- earthing of the propeller shaft to counter intermittent electrical contact between the shaft and the hull. This technique reduces the AC electric and magnetic signature. Non-conducting fibre composite propeller shafts [33] may also achieve the same effect;
- Vrbancich [34] has suggested that the static electric field signature of a vessel could be reduced by an impressed current cathodic protection (ICCP) system;
- to counter AC fields, 60 hertz power cables require shielding;
- the use of similar metals in the hull, propeller shaft and any hull mounting will minimise the DC electric field component.

3.7 Magnetic Field

The majority of mines are magnetically triggered [14]. A vessel's magnetic field may have both an AC and DC component, giving a vessel or a class of vessels a distinct magnetic signature. Modern warships undergo deperming and incorporate degaussing coils to counter any DC magnetic field produced by the vessel.

Modern degaussing systems incorporate sensors that provide a closed loop degaussing system that constantly adjusts the degaussing field in real time to minimise the magnetic field. This degaussing method can control longitudinal and vertical components. However, only DC magnetic fields are controlled this way. Degaussing alternating fields require active control and further work is needed in this area.

Resident magnetic fields are minimised if vessel construction uses non-magnetic materials such as fibre composites, plastics and non-magnetic metals, e.g. aluminium and certain grades of stainless steel.

3.8 Acoustic emissions

Minimising acoustic emissions is important because acoustic sensing is used to detect and identify vessels. Existing technologies to minimise noise generation or transmission of the noise to the sea include:

- the application of decoupling tiles below the waterline to reduce the transmission of hull/machinery generated noise into the water;
- balanced rotating equipment to minimise the generation of noise;
- floating and tuned equipment platforms and mountings;
- sound proofing;
- micro air bubble ejection from the hull surface. This dampens the noise produced from water flow over discontinuities along the hull and past the propulsion system;

- quieter propulsion systems, e.g. water jets are typically 10 dB quieter (60% lower signature), compared to conventional propellers operating at 20 kts [35];
- shrouded propellers that acoustically isolate the propeller from the hull reducing induced hull vibrations;
- larger slower propellers to reduce hull vibrations and cavitation.

3.9 Smoke Generation

The generation of engine smoke can be minimised due to efficient combustion achieved through engine design and management systems. Furthermore, cooling of a vessel's exhaust with water spray may also reduce particulate emissions.

Some systems being developed for naval power plants will not produce smoke, e.g. fuel cell power systems. However, there may be a need to generate smoke for obscuring the sight of the vessel to coastal fire observers. This smoke could be produced in the hot exhaust of the vessel or by chemical smoke flares designed specifically to obscure visible and IR transmission.

3.10 Retro-reflections

Retro-reflection is the return of an interrogating light (usually laser) signal from the focal plane(s) of optical components to the source of the light [36]. This technology allows identification of equipment from which a return signal is obtained. Attacking missiles could monitor retro-reflections to locate targets thereby defeating electronic countermeasures and decoys. Retro-reflection can be minimised through improved optical design.

4. Survivability

Survivability is defined as *"the ability to survive a military attack"* [37]. All RAN vessels should incorporate technologies and processes to survive damage, whether from battle or otherwise[5].

4.1 Fire

Protection against ship fires must involve a comprehensive analysis of the risks involved and a systems approach in managing the risks. The future will see a move away from ozone depleting halogens to water mist and other environmentally acceptable fire fighting agents. The choice of materials used in ship construction will be strictly controlled to minimise the risk of fire. In addition, the overall design of the ship to facilitate fire fighting and control known risks will be extremely important. There will be developments in automatic fire detection and fire fighting technology. These will include:

[5] >90% of fires on ships occur in peace time. [38]

- wider use of smoke detectors[6], in particular accommodation and weapon bays;
- improved designs in water mains systems making them more robust against damage and providing greater distribution of water mist heads;
- the use of flow control valves to protect against pipe rupture or breaks;
- control of power distribution about the vessel to enable isolation of fire incident areas;
- decision aids in predicting fire growth and in fighting fires, e.g. Fire Maid [39];
- improved location and access to damage control centres away from likely missile strike areas;
- distributed miniaturised televisions with IR capability to record events and aid in assessment of fire and fire fighting;
- improved personal breathing apparatus and fire proof clothing.

The future will also see further development of fire resistant composite materials suitable for structural [40] and non-structural components. These materials are particularly suitable for lightweight superstructures. Fire resistant and charring paint systems will be used on flammable materials.

Another aspect that will lower fire risk will be any future move to electric systems and localised miniature electro-hydraulic systems where less hydraulic fluids and piping are used.

4.2 Nuclear, Biological and Chemical Warfare

The capability of an adversary (even with a relatively low technology base) to produce and discharge a chemical, biological or radiological (CBR) weapon at a vessel is real. Survivability will be achieved by remote sensing of CBR agents combined with the vessel's ability to hermetically seal itself (possibly pressurised) and filtering of incoming air[7]. The capability to automatically wash down the outside of the ship with an appropriate decontaminant would also be required. It is expected that compact, sensitive and automatic remote sensing technologies will be developed for CBR agents, such as laser scanning systems providing remote analysis of the atmosphere. Portable miniaturised chromatograph technology [42] will enable almost instantaneous chemical analysis of samples.

4.3 Armour Protection

Advances in the armour penetration performance and effective range of small arms ammunition in the last decade have challenged the adequacy of existing ship armour

[6] Smoke detectors are not used throughout RAN vessels [38]

[7] A pressurised citadel would probably only be needed for accommodation and command areas in much the same way the Danes are considering for there surface combatants [41]. The rest of the vessel would only need a slight over pressurisation to provide NBC protection.

protection standards (which are long established) for magazines and other vital areas. Machine guns or sniper rifles, the latter up to 0.50 calibre, now offer an adversary a means of achieving 'cheap kills' in low intensity operations. This is especially the case for vessels involved in amphibious movements, as they will spend a lot of time close to shore.

New developments in ultra-lightweight armour technology are expected to give protection against armour piercing ammunition. Such armour would likely consist of synergistic combinations of fibre-matrix composites, ceramics, high hardness steels and new grades of low-cost titanium [43].

4.4 Underwater Explosion/Shock resistance

The predominant damage mechanism to a ship's structure or internal equipment from an underwater explosion is the initial shock loading. Attenuating the peak overpressure will reduce material strain rates and structural and component accelerations thereby enhancing survivability. *Rude et al* [44] have completed some investigations which show that elastomeric materials such as neoprene attached to the wetted surface of hull plates afford some attenuation of the transmitted shock wave. This technology could replace some traditional shock resistance design features resulting in construction cost savings. Conversely, this procedure may be suitable to improve the shock resistance of older vessels.

Commercial-off-the-shelf (COTS) equipment is also an area where cost efficiencies can be made. Traditionally mission critical equipment used in naval vessels must be shock qualified to MIL-S-901D [45] or an equivalent standard and as a result tend to be expensive. If critical equipment can be isolated from the shock motion by shock attenuating mounts, less shock resistant and less expensive (COTS) equipment can be utilised.

Future developments may see the use of active shock mounting in critical areas. This technology has been developed for protection against earthquakes [46] and could be applied to mitigate against shock from undersea mines.

4.5 Battle Damage Control and Assessment

In the advent of damage to a vessel either by fire, mines or blast, the damage control systems need information about the extent of damage to provide an efficient and effective response. Computer models of scenarios combined with artificial intelligence will be able to assist damage control personnel in assessing the level of battle damage. Remote sensors, e.g. water-level, smoke, heat and pressure, will be able to feed real time data to assist the damage assessment. These sensors could also allow automation of damage control operations. Automatic fire fighting systems will turn sprinklers on or off as required, ventilation could be controlled to slow the spread of fire or clear smoke and pumps could automatically start or stop depending on water levels.

Miniaturised solid state cameras throughout the ship would feed real time video images from damaged areas and provide records of events for later assessment.

4.6 Electromagnetic Pulse Weapons

The increasing dependence on electronic technology for command, control, communications and intelligence (C3I) and COTS products increases a vessel's vulnerability to electromagnetic pulse (EMP) weapons.

EMP weapons produce a large electromagnetic pulse of energy much like that of nuclear weapons detonated in the atmosphere[8]. However, EMP weapons use non-nuclear means to produce the energy [47]. Unprotected electronic equipment will receive energy via cables and aerials destroying electronic components and disabling computerised systems. Delivery can be by missile or aircraft but these weapons could be small enough to fit inside artillery shells [48].

Protection against EMP is achieved by a systematic design in shielding and providing protective devices to all vulnerable inputs, e.g. aerials, cables, sensors. Complete protection is probably not feasible due to the cost but high priority systems should be able to be protected with a high probability of survivability.

4.7 Direct Line of Sight Weapons

Direct line of sight weapons refer to weapons that transmit energy in a straight line without gravity affecting aim. High power lasers and masers are such weapons, where the projected energy travels at the speed of light.

4.7.1 Lasers

Using current and future technology, a high power laser weapon used against a ship would be directed towards the destruction of electro-optic sensors. Such a weapon may be carried on an aircraft, directed from another vessel or from shore. Future technology will see higher powers of laser energy being generated but the powers needed to significantly damage a large ship are not foreseen in the next 10-15 years[9].

Electro-optic sensors can be protected by optical band-pass filters or special high energy limiting filters that absorb and reflect the energy during attack.

4.7.2 Microwave and Radio Frequency Weapons

Microwave and radio frequency weapons use pulsed electrical power to generate the pulse of radio or microwave energy. These types of weapons require a compact high-energy power source which may be achieved with advances in homopolar generators,

[8] Nuclear testing by the USA at Bikini atoll disrupted and damaged radio equipment in Hawaii more than 6,000 kms away during the 50's.

[9] The energy supplies to power the laser would also be substantial.

fuel cells and explosively driven energy converters (chemical to mechanical to electrical energy). Weapons delivery may be by missile, aircraft or fired from artillery.

5. Self-protection

A review of modern amphibious assault ships, e.g. LPD 17, reveals a move to the provision of self-protection on such ships. This would appear to be a logical step as afloat support vessels are high priority targets.

Special design considerations will exist for replenishment vessels, e.g. the provision of self defence anti ship or anti air missiles will increase the risk of explosion or fire onboard. Nevertheless, it is expected that technical advances in wide area surveillance and self defence will enable all afloat support vessels to have an adequate self defence capability in the future.

5.1 Area Surveillance

Any future naval vessel whether in a convoy or travelling alone will require wide area surveillance against enemy vessels, missiles or aircraft. In fitting with the need to have a wide area surveillance capability, the ADF has developed a wide area surveillance strategy that will employ a variety of sensors [49]. These sensors will vary between broad coverage with low to extremely high resolution of significantly large areas.

Technology will enable future afloat support vessels (and all suitably equipped RAN vessels) to call upon a multitude of sensors providing a breadth of data varying in type, resolution and fidelity. These sensors will be air, space, land and sea based and all their information will be fused to provide a co-operative engagement capability[10]. This will require fitting the vessels with the appropriate level of communication equipment.

5.1.1 Space Sensors

Australia is currently considering acquisition of a surveillance satellite under Defence project 2044 [51]. Most probably located in a low orbit (160-500 kilometres)[11], such satellites will provide real time multi-spectral imaging of land, air and sea areas of interest. With an image width of ~ 320 kilometres and daily coverage, land forces, ships, aircraft, missiles and submarines will be detectable.

Even without its own satellite, Australia can buy Landsat or Spot multi-spectral images that offer resolutions down to 3 m or better. Commercial satellite systems launched in 1997 have images with 1 m or better resolution (Table 3).

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[10] Co-operative engagement capability means a networking of all combatant sensor inputs. The inputs are fused together to provide a common battle picture to all members of your force. For example, the data from an AEWC hundreds of kilometers away can be viewed with the local radar coverage input [50]

[11] Stationary orbit surveillance satellites (~ 40,000 kilometer orbit) are increasing their resolution and capability but will probably never have the resolution of the low orbit satellites.

Table 3 Resolution of commercial satellite systems with relatively high resolution [14]

System	**Best Resolution**	**Positional Accuracy**	**Passes/day**
Space Imaging (SI)	BandW : 0.82 m Multi-spectral: 3.28 m	1.5 m	1.82
Earth Watch (Early Bird) (Quick Bird)	BandW: 1 m Multi-spectral: 4 m	<20 m [52]	1.15

Other satellites that can provide environmental data are listed in Table 4 which would enable rapid environmental assessment before afloat support operations.

Table 4. List of satellites and their characteristics [53]

Satellite	Country	Sensor	Resolution	Cycle	Measures or images
NOAA	US	passive radiometer	1.1 km	twice daily	sea surface temp, fronts, eddies, upwellings
ERS-2	European Space agency	side looking imaging radar, passive radiometer, altimeter, side looking radar	25 m-100 m 1.0 km 16 km 45 km	3, 35, 176 days 35, 176 days " "	ship/wakes, currents wind speed and direction, rain, surface roughness, bathymetry. Sea temperature, fronts, eddies, upwellings. Significant wave height, sea surface height, currents and wind speed. Wind speed and direction.
RADARSAT	Canada	Side looking radar	12.5 m	5 days	oil spills, ship/ wakes, swells, currents, fronts, wind speed and direction, internal waves, rain, surface roughness, bathymetry.
TOPEX/ POSEIDON	US/France	Nadir looking radar	7 km	10 days	Sea surface height, currents, wind speed, significant wave height.
ADEOS	Japan	Side looking Radar	50 km	2 days	Wind speed and direction.
DMSP	US	Passive Radiometry	50 km	Twice daily	Wind speed.

5.1.2 Land Based Sensors

One system providing wide area surveillance is the Jindalee Operational Radar Network (JORN) providing over the horizon radar out to 1000-3,000 kilometres [49]. The current coverage is to triple as it is pointed more to the North [Figure 12].

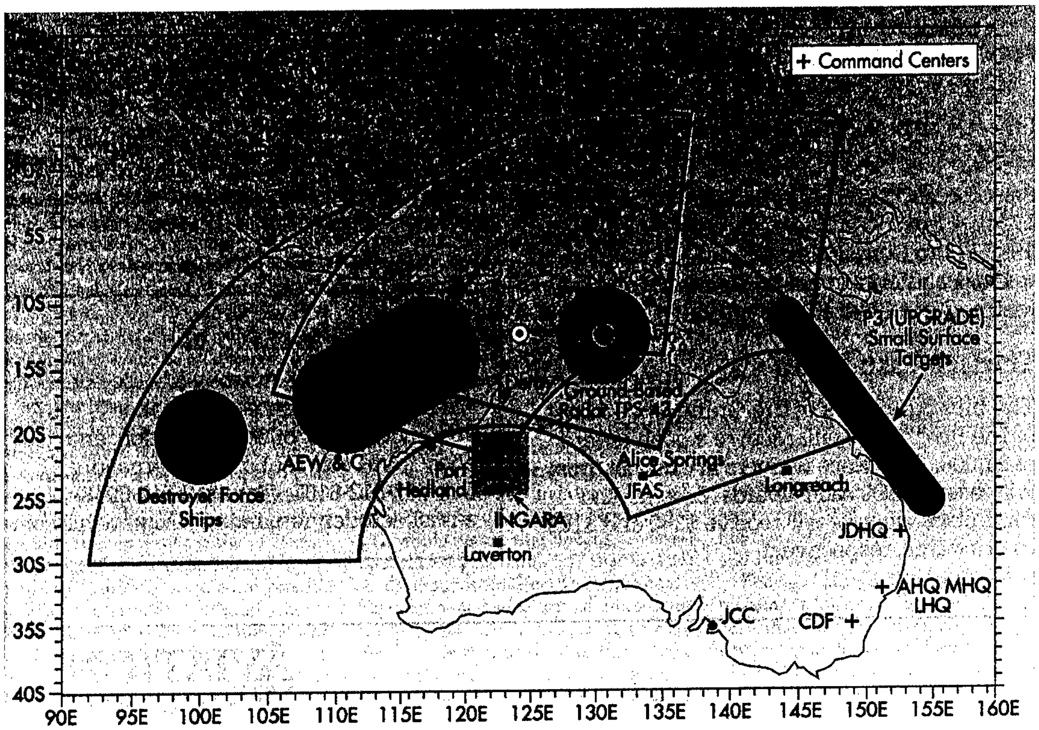


Figure 12. Wide area surveillance proposed for Australia [49]

Other land based surveillance will include the ADF Northern Command (NORCOM) radar based at Darwin (Figure 12).

Using existing technology, JORN and the NORCOM radar data could be fused and transmitted to future RAN vessels as part of a co-operative engagement capability. Conceivably, all coastal radar stations could contribute to a co-operative engagement capability.

5.1.3 Air Based Sensors

Air based sensors offer the advantage of being able to see over the horizon. Current and future air based sensors that could contribute to the co-operative engagement capability providing wide area surveillance include:

- radars, forward looking infra red (FLIR) radar and other sensors on RAAF fighters and other aircraft;
- surveillance aircraft, e.g. P-3 Orions;
- planned airborne early warning and control (AEW&C) aircraft [49];

- unmanned aerial vehicles (UAV), and
- lighter than air vehicles and kites.

All of these aerial platforms can feed their sensor data into a co-operative engagement capability system.

The capability will exist for an RAN vessel to carry its own sea launched and recoverable UAV with its own sensor package. Such UAVs can be launched and landed vertically [54,55] or alternatively fired off the vessel by such means as a catapult [23] and retrieved by net. Vertical launched and landing UAVs are preferred by the USN after trialing due to the space required for non vertical take-off and landing UAVs [56]. The German Navy is also funding a vertical take-off UAV designed for maritime work[12] called the Seamos (Figure 13) [57].

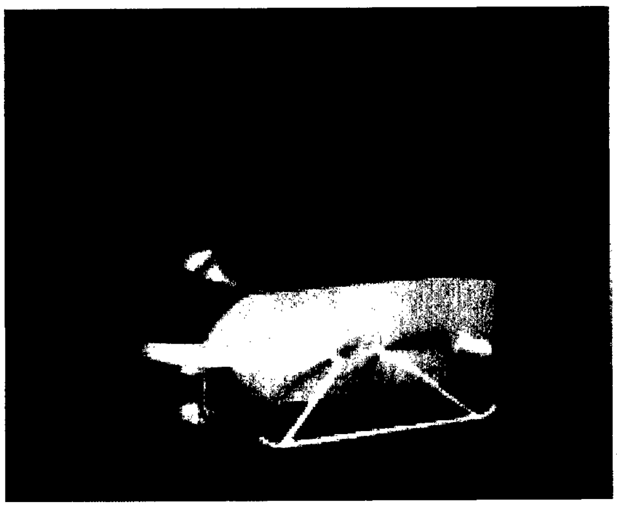


Figure 13. The Seamos maritime UAV [57]

UAVs would be particularly advantageous in littoral waters where they can scan the coast and inland using visible, IR and image intensified television to provide real time situational awareness. Using a rangefinder linked to the UAV's internal GPS, naval and other supporting fire can be accurately directed. Final targeting could be achieved using a laser designator [58].

Other uses of UAVs could be provision of wide area surveillance for vessels at sea. High altitude, long flying endurance UAVs such as the Tier II+ High Altitude System are currently being developed by the Defence Advanced Research Project Agency (DARPA) [14]. These UAVs will be stealthy and have long range sensor systems such as Synthetic Aperture Radar (SAR), IR sensors or LPI Radar. One new type of sensor being marketed for land use but would have a significant impact as an airborne sensor in a UAV, is a radio receiver that detects humans [59]. It detects the ultra low frequency radio emission from the beat of the human heart and can discriminate between humans

[12] The German Navy has already demonstrated automatic vertical landing and take-off from a moving ship in 1991 [57].

and animals. With a reported 500 metre range in an uncluttered environment, detection of humans in day or at night by aerial surveillance would appear to be a possibility.

Surveillance would cover the sea, coast and inland areas. UAVs may be powered by the sun [60] or have in-flight refuelling capability [14]. The data obtained would be fed back to the vessel(s) for use in a co-operative engagement capability system. Alternate systems may include a co-operative assembly of UAVs consisting of a large UAV radar transmitter with small very stealthy UAV receivers flying over enemy territory [14].

Lighter than air (LTA) vehicles and kites are being investigated by many countries to provide long range surveillance. In particular, the US marines have examined the use of a tethered airborne-surveillance system to provide the long range inland surveillance at beach heads to aid JLOTS and amphibious assaults [61]. Such LTA vehicles could be tethered from an amphibious assault vessel, and also provide air surveillance for the convoy during transit to and from the area of operations.

5.1.4 Sea Based Sensors

Sea based sensors will comprise acoustic, electronic and electro-optic sensors, the latter providing passive sensing when covert/stealth operations are required.

5.1.4.1 Radar Systems

Radar requirements for afloat support vessels vary from the open sea to littoral conditions. Unlike the open sea, the littoral environment warning times can be extremely short. This is due to the ability of missiles and aircraft to arrive from over the coastal horizon and the increased potential for jamming and clutter conditions. There are also atmospheric effects that make it difficult to minimise false alarms and identify weapon systems.

Current radar employed by the RAN is at the sea surface and is horizon limited. This limitation could be minimised by air coverage beyond and above the horizon. Radar is traditionally active and highly detectable, and ships using radar will readily reveal themselves to a monitoring radar before it can detect the enemy itself. However, the development of LPI radar enables a vessel undertaking radar surveillance to have a high probability of remaining undetected. The vessel is likely to detect any electronic signal monitoring (ESM) sensor before it is itself detected [62].

5.1.4.2 Technologies Associated with Radar

Some of the technologies available now or expected to be available in systems by 2010-2015 include:

- high power solid state electronics replacing travelling wave tubes (TWT);
- tracking of multiple (~1000) targets;
- true 3 D display enabling display of subsea, surface and aerial craft [63,64];
- replacement of rotating radar dishes with steerable solid state arrays (providing increased reliability and scanning speed);

- faster processors and digitisers for returning radar signals (these are developing continuously);
- smarter algorithms to remove clutter, reduce false alarms, identify target and provide motion analysis;
- telescopic masts to decrease vessel's radar cross-section when required;
- enclosure of radar masts within fibre composite structures, Figure 14. Fibre composites can have windows for specific radar frequencies and absorb others [65]. Smart material development might allow future materials to be switched from radar window condition to radar absorber. This technology is also expected to decrease radar maintenance.

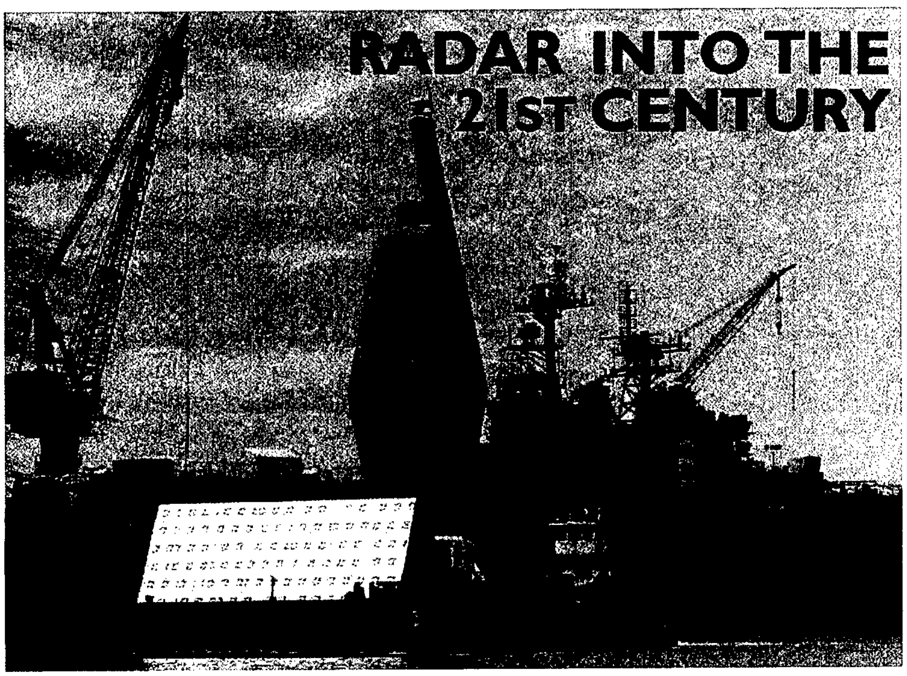


Figure 14. Prototype fibre composite radar mast [65]

5.1.4.3 Electro-optic Sensors

Electro-optic or optronic sensors are usually associated with daylight, low light level televisions and IR imaging devices that can help confirm radar tracks. However, optronic devices can replace radars in some areas of search and detection of surface and airborne targets [54].

In littoral waters, electro-optic sensors (particularly thermal imaging) distinguish targets and missile launches against land backgrounds that would otherwise confuse a radar. They can also detect and distinguish small fast boats where surface search radars have difficulties. Consequently, optronic sensors provide more time to engage a target with a higher probability of tracking [54].

Even in the open seas, optronic sensors are aiding ship defence tracking radar. These radars can suffer from multi-path propagation effects with low flying aircraft and missiles. Such sensors usually have 2-3 times the resolution of radars. They are also multi-band IR devices providing good target discrimination.

It is expected that passive electro-optic sensors will become more important due to their inherent stealth features. They will become more compact and achieve higher resolutions and sensitivities. With increased data rates, high speed data processing will occur within the sensor with high speed processors running target discrimination and automatic target recognition software. This will decrease data transmission requirements and response times.

5.1.4.4 Sonar

During operations a vessel will generally use passive sonar in order to remain covert. Passive systems will include hull mounted and towed array sensors. Detection of submarines or surface vessels will depend on many factors, e.g. type and number of sensors, sensor sensitivity, self noise of the vessel, signal processing, etc. It is highly probable that afloat support vessels will have some form of hull mounted sonar system linked into a co-operative engagement capability (CEC) system. Sea bed mounted radar arrays may also provide information to the CEC.

Greater understanding of the ocean environment may provide opportunities for the equivalent of large base line interferometric acoustic systems to improve spatial resolution using ship mounted sensors from widely dispersed vessels.

Littoral warfare inevitably means operating where there is minimal sonar coverage, so small miniaturised sonar arrays deployable on the sea bed from a vessel would be useful. USN systems such as the advanced deployable system and the fixed distributed bottom system provide horizontally deployable systems but vertical systems have yet to be developed [14].

Sonar sensitivity is expected to increase by between 10 and 15 dB at a predicted rate of roughly 1 dB per year [14]. However, the greatest gains will probably be in the onboard computer processing of the signal to yield location, speed, direction and identification of detected vessels.

The technology for bi-static sonar could improve with the use of high powered expendable sonar emitters that could be deployed at significant distances from the vessel by dropping from aircraft (e.g. UAV, helicopters), or fired from the vessel.

5.2 Missile Protection

Future anti-ship missiles will become stealthy and "smarter". Their final speed will be hypersonic and their final targeting mode may follow a random course to defeat predictive anti-missile systems. Their sensors will be multi-band using active and/or

passive means to locate and discriminate the target from decoys or electronic counter measures.

The ability to defeat missiles will rely on early detection, rapid target recognition and tracking, and rapid reaction defensive and decoy systems acting in a co-ordinated and co-operative manner. One such system is the integrated Ship Self Defence System (SSDS). Developed for US Naval vessels operating close to shore, the SSDS integrates numerous ship board systems for defence against anti-ship missiles [66]. It integrates or will be able to integrate such systems as:

- SPS 49 air-search radar;
- SPS 67 surface-search radar;
- Mk. 36 "soft kill" decoy launcher;
- Phalanx, close in weapons system;
- Rolling Airframe missile;
- NATO Seasparrow;
- Evolved Seasparrow missile (ESSM);
- Nulka, the radar jamming decoy;
- ESSM launched from a quad pack of the MK 41 vertical launch system.

5.2.1 Anti-missile Missiles

Recent developments in missile defence systems against missiles (and aircraft) have seen a move away from steerable launching platforms to (multiple) vertical launch systems (VLS) shown in Figure 15. This simplifies the missile handling system within the vessel, reduces system size, increases reliability and eliminates the time delay to load and point the weapon in the direction of the threat [67].

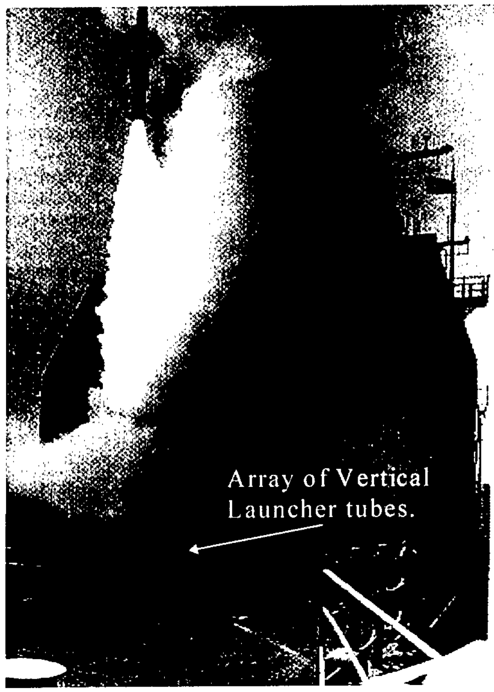


Figure 15. A vertical launch system [68]

5.2.2 Close-in Weapon Systems

Close-in weapon Systems (CIWS) provide the last point of defence against missiles and aircraft engaging at distances of roughly one km. Future CIWS will require increases in accuracy and reaction time to detect and engage the next generation anti-ship missiles which will be faster, stealthier and more difficult to track. Improvements may be achieved by adopting an integrated system design, improving the fire control and programmed ammunition feed.

Existing CIWSs usually involve Gattling gun systems incorporating multiple rotating barrels. These are high rate of fire (~4000 rounds per minute) gun systems using bursts of high density penetraters to destroy incoming anti-ship missiles. The radar system tracks the incoming missile and the out-going penetrater fire, a closed loop servo control system, corrects the gun aim on subsequent bursts.

5.2.2.1 Metal Storm Technology

Metal Storm is a gun system (Figure 16) capable of an infinitely variable rate of fire up to one million plus rounds per minute [69]. Firing is electrically initiated using computer control and applications of this system could be in CIWS. The gun system has no moving parts and no ammunition feed or ejection system nor any breech opening. These factors not only contribute to the high rate of fire but also suggest significantly improved reliability, reduced weight and minimisation of through life costs.

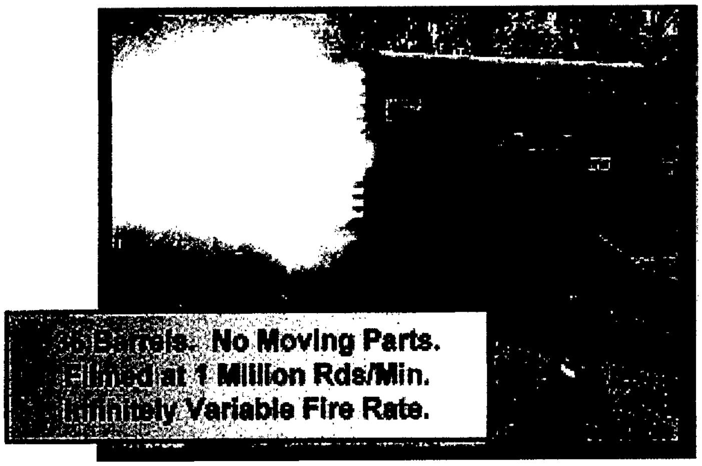


Figure 16. Metal Storm technology demonstrator [69]

5.2.3 Electronic Warfare

Electronic warfare utilises the force of electronic signal strength as a weapon or a means of deception. In either case, it is believed that all current and future naval vessels will require electronic self-protection as a soft kill option in comparison to hard kill ammunition based systems. Electronic warfare systems require time to react to and interact with threats, however, with increasing missile speed, future electronic warfare systems will need to operate automatically upon identification of a threat and the system will need to be fully integrated with any surveillance and target identification system.

Deception techniques are continually developing and may be ship based, deployed from helicopters or floated or flown away from the vessel. Some of the systems currently available are

- the Nulka hovering rocket. This rocket technology could be replaced by jet engine technology (similar to jet belt technology) to achieve a multi-use system. This jet technology could allow the decoy to deploy for a longer time (~30 mins) and return to the vessel for refuelling and reuse. (see Section 2.3.6 on Jet packs);
- remotely piloted helicopter (RPH) e.g. Sprite [61] or small autonomous helicopter that can hover and slowly move away from a vessel;
- expendable active off-board decoys propelled from a vessel, deploy a parachute and float upon the water e.g. the LURES system [70].

5.2.4 Direct Line of Sight Defensive Weapons

High energy Lasers and Masers are weapons that can be used against high speed missiles, aircraft and UAVs because they are direct line of sight weapons. This technology can provide quick responses and speed of light transmission of energy

from the laser or maser to the attacking missile. This weapon does not have to predict where the missile will be, it only has to maintain its aim.

5.2.4.1 Lasers

Laser technology has been an area of research for many years and the tactical high energy laser (THEL) weapon developed in the USA is being tested with Israel as a Katusha missile defence [71]. This system is a 1 MW laser and could be mounted on a naval platform.

Future developments in this field may involve solid state laser technology where distributed arrays of high power semi-conductor lasers are used (with solid state steering of the beam eliminating mechanical systems). Such technology offers the potential for higher energy conversion efficiencies. Systems distributed around a ship would minimise vulnerability and using solid state technology, reliability would be high. This technology would have implications on the size of electrical power systems. Nevertheless, it is believed solid state weapons could readily be employed on afloat support vessels.

5.2.4.2 Masers

Maser is an acronym for microwave amplification by stimulated emitted radiation. This is essentially a laser but operating in the microwave region of the electromagnetic spectrum. High power microwave weapons may be available by 2010, however existing high power technology enables the production of multi-megawatt pulses of radio energy [47]. This energy directed towards attacking missiles, UAVs or aircraft will couple with the target's electronics through antennae, sensors or inadequate electromagnetic screening. The radio energy can disrupt or destroy electronic components resulting in a loss of guidance control and unstable flight.

5.3 Aircraft: Protection Against

Future aircraft attack against ships will be by long range missiles, with the aircraft not required to get close to the target to engage. However, the Falklands conflict showed that in littoral waters, vessels were within the radar/sensor shadow of the coast line and attacking aircraft had to visibly sight the target. The aircraft were also shadowed from radar or other sea based sensors. Until continuous wide area surveillance can be obtained this deficiency in threat detection will be present and vessels must be able to defend themselves against such attacks. The type of defensive systems to protect against this type of attack will include:

- hypersonic VLS missiles, (>mach 4);
- counter electronic warfare systems;
- laser (dazzle and destructive), microwave systems;
- CIWS

5.4 Mines: Protection Against

Due to their shallow depths littoral waters are ideal places for mining, and prior to an amphibious lodgement, the risk of mines would need to be appraised[13]. If considered necessary, mine clearance divers or minehunter vessels would need be employed to clear beaches and channels.

In RAN operations there will probably be a move to an integrated systems approach to mine detection and avoidance similar to that being adopted by the USN. In this scenario, future afloat support vessels will likely have some local capabilities such as mine avoidance sonar. More sophisticated technology such as swim ahead semi or fully autonomous vehicles[14] will be handled by the escort vessel designated to provide mine detection.

5.5 Torpedoes: Protection against

Very sophisticated technology is used in torpedoes providing a weapon that can discriminate between multiple targets, track targets by acoustic and wake signals or be guided by targeting telemetry fed over a fine wire. However, today's torpedo defensive technology appears to be relatively crude.

Afloat support craft such as amphibious assault, sea cargo and tankers will all be prime targets for torpedo attack. Modern torpedoes are able to specifically target these vessels amongst escort vessels. Thus consideration must be given in supplying these vessels with means of defending themselves against torpedoes.

5.5.1 Torpedo Decoys

Torpedo decoys aim to mimic the acoustic signal of the target and decoy the torpedo away from the target where it will either hit the decoy, delay the torpedo giving the target an opportunity to outrun it or lose the torpedo. However, modern torpedoes are also becoming smarter and can switch to active sonar targeting in the final stages and ignore decoys.

Current developments in decoy technology involve mobile decoys that have limited capability. Future developments will see:

- smart mobile decoys that mimic wake and acoustic signatures of the vessel;
- expendable acoustic decoys that are not towed behind the vessel like some current decoys;
- noise makers that will raise the ambient noise level so high that target discrimination by the torpedo is impossible.

[13] Reconnaissance of the beach is standard procedure before amphibious assault or lodgement.

[14] Semi autonomous vehicles are available now where the vehicle is connected to a vessel by a command link (wire or fibre optic cable). The diesel powered snorkel equipped Dolphin is an example of this [14]. Fully autonomous vehicles will appear in the future.

5.5.2 Torpedo Defence Systems

The hard kill of an attacking torpedo is very difficult due to the robust nature of torpedo design, its high speed and the difficulty in accurately tracking its course. They can also be difficult to detect. Modern detection systems use multiple sensors mounted on a platform and towed behind [72]. It is expected that this technology will become more sophisticated as algorithms, sensors and processing speeds constantly improve. Modern torpedoes can travel deep (~80 m or more) and remain below water layers before rising steeply and targeting the most vulnerable areas of a vessel. Nevertheless, some of the technologies currently being looked at include:

- anti-torpedo torpedoes;
- underwater hyper velocity projectiles using super cavitation to attain very high speed. This weapon would be an underwater analogy to a CIWS.

5.6 Shore Batteries: Protection Against

Possible protection against artillery and rocket fire from shore or even from other ships may be obtained by using electronic jamming against radio frequency (RF) proximity fuses used in some of these weapons [73]. Already available for land use, the technology could be extended offshore.

5.7 Offensive Weapons

5.7.1 Naval Artillery

Ship mounted gun system hardware will be stealthier with angular sided turrets constructed from non-magnetic materials to reduce radar and magnetic signatures [74] (Figure 17).

Ammunition range will increase to allow engagement of high velocity missiles at greater distances. This will be necessary to reduce fragmentation damage caused as a consequence of target detonation at close ranges.

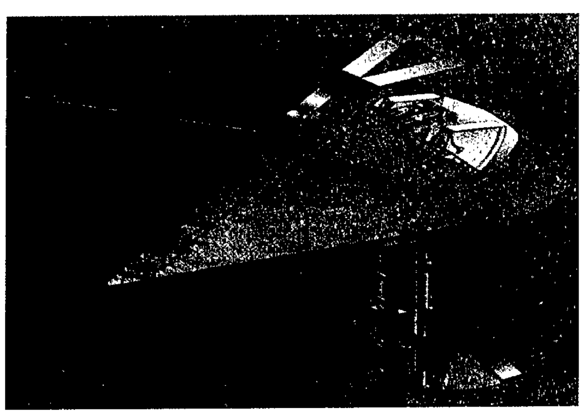


Figure 17. Naval Artillery incorporating stealth technology [74]

6. Command. Control, Communications, Computers and Intelligence

6.1 Command and Control Facilities

It is likely that any future amphibious assault vessel would be equipped for a joint force commander and staff in an afloat joint force headquarters facility. Such a facility should have sophisticated communications, and command and control capability together with the ability for surveillance and other intelligence information. Future systems will obtain information in real time, operate co-operatively with other (remote) systems and present information in real time. Some of the future developments are discussed in the following sections.

6.1.1 Co-operative Engagement Capability

One of the more promising systems being developed (by the USA) is the Co-Operative Engagement Capability, a system linking all fleet defensive systems together. In essence, any sensors within a convoy or battle fleet, can be linked together with air and land based sensors enabling wide area surveillance where each component is able to see what every other component can see. In addition to extending the sensor range of a vessel, the system also allows the exchange of integrated fire control data in real time, improving electronic warfare countermeasures and extending defensive systems capability.

The system is based around an open architecture that allows the maximum use of COTS equipment and the ability to quickly upgrade with improvements in processing capability and miniaturisation.

An example of its capability is the case of a vessel in littoral waters undertaking JLOTS. Aerial platforms (e.g. UAV) can survey the inland region, other vessels the coast line and sea, and AEW&C aircraft the ocean beyond the radar horizon. Sea skimming missiles can be detected by the AEW&C and the tracking and location communicated to every vessel. The most appropriate vessel can be detailed to deal with the threat even though it cannot yet detect the threat itself.

6.2 Communications

Communications continuity and wide bandwidth will be future requirements for peace time and active operations. During the Gulf War, US forces relied on commercial networks in addition to the their own dedicated communication links to obtain the necessary bandwidth. Part of the problem was due to real time intelligence such as satellite images which required large chunks of the available bandwidth. The future implications for afloat support will be somewhat similar in that increasing data transfer will fill and exceed the current and future available bandwidth.

Communications will move toward digital technology allowing higher clarity in voice communications, automatic error correction resend, image transmission, and compression techniques, e.g. such as fractal compression, potentially allowing 100 to 1 compression or more.

Continuous wide band secure *line of sight* communications between vessels and even between vessels and UAVs and other aircraft will be available using laser technology[15] allowing them to remain covert. This would be useful en-route to an operational area where interaction, e.g. training and planning can be maintained between vessels when such communication by radio would normally not be allowed.

6.2.1 Space

Space offers many advantages for communications and intelligence. There are many types of satellites including:

- surveillance (radar, IR, UV and visible wavelengths);
- electronic intelligence (ELINT);
- global positioning;
- weather (wind [75], rain [76] , tides and temperature measurement);
- communications (digital, radio, telephony, emergency beacons and television).

The number of satellites, the quality of their output and communication band widths, will all increase due to:

- commercial and government demands;
- higher power handling and miniaturisation of electronic components;
- smaller satellites (e.g. lightsats);
- higher frequency communications;
- more efficient electronics;
- better optical sensors;
- smart antenna design;
- use of COTS and cheaper launch systems.

6.2.1.1 Global Positioning System

The ability to accurately determine position is achievable today with the advent of the global positioning system (GPS). Advances to come in this area are:

- jam proof GPS (it is within the capability of many countries to jam the existing GPS system now if not in the foreseeable future);
- miniaturisation of the system to watch size (breadboard prototypes have already been produced).

[15] Laser communication idea suggested by Stephen Boyd of Maritime Platforms Division, AMRL, Melbourne

6.2.1.2 Communication Satellites

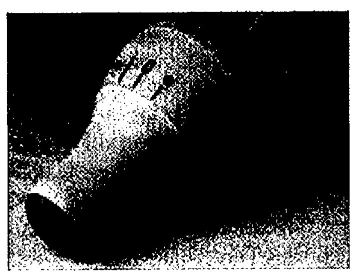
A critical issues paper on future RAN communications [77] details the specific needs of the RAN and future communication options available. The report suggests that the future is limited to commercial satellite communication systems if the ADF does not establish its own high bandwidth satellite links. Without a high bandwidth link (suggested to be X-band) the future options involve using the following commercial systems:

- INTELSAT (regional and global coverage with links up to 1.544 megabytes per seconds);
- INMARSAT with links up to 64 kilobytes per seconds (restrictions on military use);
- PanAmSAT which has been used to provide 256 megabytes per seconds links to HMAS Success.

Even with a suitable communication satellite link, in time of need the bandwidth may still prove to be insufficient requiring use of existing commercial global networks. This proved to be the case in Desert Storm where the US forces found that the existing tactical links were insufficient and commercial networks had to be used. Therefore the ability to link into these future global services would be a prudent measure for any future communication system for afloat support.

6.2.1.3 Onboard and Ship-to-Shore Communications

Normal ship wide communication on board a vessel is by a public address (PA) system. However, future communications may involve personal pagers or even personal miniaturised one way earpiece radios [78] (Figure 18) or telephones that could be switched to extend offboard the vessel for personnel transiting to and from shore or for those ashore.



18. Miniature earpiece radio Figure device [78]

The logging of personnel on and off a vessel will likely be by personal identification dog-tags using technology that already exists thus providing a real-time status of personnel onboard the vessel. Technology may advance where these dog-tags can also include a locating and recall capability and ultimately personal communication.

6.3 Computers

Today computer technology is all pervasive and the future will see no change. There will be continuing miniaturisation and increases in computational speed and power.

The increasing use of portable computers by soldiers will have implications for troop transport in the provision of recharging facilities for batteries associated with these systems. Computer communications will be an everyday requirement for general ship to shore interaction such as email for personnel, individual training and wargaming.

6.3.1 Training

Training is one area where computers will make significant impact in reducing costs. By modern high density digital links, vessels will be able to link together with shore installations to undertake wargaming. The digital links will allow in situ training of personnel working in a co-operative environment although vessels may be separated by thousands of kilometres.

Training will also be provided by self training software packages or by email and teleconferencing over the internet. This distant learning will aim to provide "*delivery of standardised individual, collective, and self-development training of soldiers* (sailors and aircrew) *and units at the right place and right time through the application of multiple means and technologies*" [79].

A recent review of future training is provided by in the critical issues paper by Manzie *et al* [80]. In addition to the above, the report discussed future developments involving:

- wide availability of training modules;
- embedded training in ship board equipment;
- improved human-machine interfaces to aid training;
- structured training with automatic marking, rating and movement to advanced training;
- onboard intranet through which training can be accessed throughout a vessel;
- advanced distributed simulation using high level architecture (standardised and common with defence partners) that would allow wargaming with computer generated or semi-automated forces.

The training systems would also have intelligence embedded within them to rework areas where the student experiences difficulty until appropriate level of proficiency is obtained.

6.3.2 Decision Aids

Decision aids will be software packages that can encompass expert knowledge within a well defined area in artificial intelligence software. They will provide training and expert advice that may not necessarily be available onboard. It may entail artificial intelligence (AI) software encompassing "rules of thumb". Alternatively, the software may encompass smart algorithms to aid personnel or a combination of both AI and smart, quick processing. Some areas where decision aids may develop are:

- advice on propagation of radio and microwave radiation;

- medical advice;
- maintenance and repair of systems;
- packing and scheduling of loading and unloading for efficient JLOTS;
- maximum speed of advance considering currents, weather and conservation of fuel;
- target identification;
- prioritisation of action;
- minimising signatures;
- strategic loading of the vessel.

6.3.3 Automation, Control and Monitoring Systems

Future ships will be fully integrated using an open architecture distributed network enabling ready upgrades with the use of COTS equipment and software. Recent developments in the US has seen the emergence of component level intelligent distributed control system (CLIDCS)[14]. This system using COTS equipment allows control down to the component level in large complex systems. It *"provides local intelligence through the use of embedded microprocessors at each node (every electromechanical device) in the system, with the ability of each node to communicate directly to each other node on the control network as required, and as a result, transparent access to information and control at the component level or any other desired level"* [14]. Figure 19 shows the difference from the standard monitoring and control systems involving a loop or ring circuit and the future CLIDCS. Note that CLIDCS nodes can even be mobile.

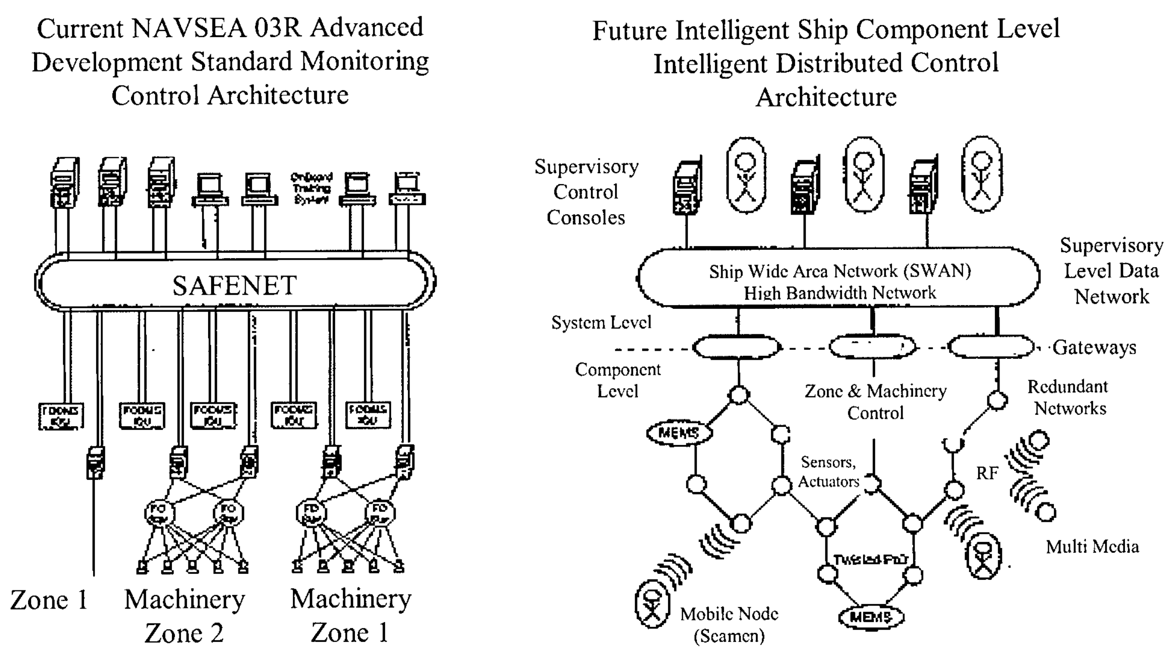


Figure 19. Comparison of current and future control system architecture [14]

6.4 Intelligence

Afloat support will need to provide facilities for psychological operations (PsyOPs) particularly in operations other than war (OOTW). Recent US experience in Haiti and Bosnia has demonstrated that PsyOPs can play a significant part in helping achieve the aims of the operation whilst minimising casualties. The type of onboard facilities needed will be [81]:

- television and AM and FM radio studio and broadcast facilities;
- pamphlet printing facilities and ability to distribute them[16];
- real-time access to the internet;
- databases on social and cultural mores;
- decision aids in negotiation (possibly intelligently linked to custom and social mores data).

7. Medical Technologies

The breadth of medical services that need to be supplied by an afloat support force vessel extends beyond the treatment of battle injuries. With emergency evacuation and United Nations operations, the capability of medical facilities need to be wide ranging. This can be achieved by modular concepts where appropriate facilities are installed to meet the operational need.

7.1 Telemedicine

Telemedicine is the concept of using modern communications and technology to aid in the application of medicine. By the use of modern communications and digital storage technology, medical data and expert advice can be readily available to the surgeon located in a remote medical facility e.g. onboard an amphibious assault vessel.

Technologies and procedures currently available or being developed include:

- meditag [82]: personal electronic dog tag for service personnel. The device holds complete medical records and medical images, e.g. X-rays;
- expert mentoring of and consultation with field medical staff via modern communication links;
- expert systems: computer software that holds expert knowledge in medical fields;
- robotic surgery: using cameras inserted into the patient and robotic arms remotely controlled, surgery can be performed remote to the patient;
- medical diagnostic imaging system. Available now for the digital capture of X-rays and other medical imagery;

[16] One possible means of distributing of leaflets over a population may be achieved by a UAV.

- mobile intensive rescue facility (MIRF) (stretcher size life support system) developed in Australia to transport intensive care patients via ambulance and helicopters [83]. This technology is also being developed in the US [82];
- advanced micro-electronic medical sensors [82];
- mobile medical monitors that monitor a patient's vital signs and records them from evacuation through to a base hospital [84];
- wrist mounted health monitoring system with miniature GPS locater system [83];
- miniature chemical diagnostic system(s) to analyse water pollution and toxicity;
- medical regulating system that keeps track of patients, their records, transport to and from vessel and type of care;
- a patient tracking system (possibly using the electronic dog tag) that links into the medical regulating systems and enables automatic recording of ingress and egress from medical and other facilities;
- table top nuclear magnetic resonance machines [85];
- ability to remotely monitor, configure and control a remote telemedicine system [86].

The implications for medical facilities on RAN vessels are:

- allocation of digital radio/satellite links with suitable bandwidth;
- onboard power for digital systems associated with the telemedicine technology systems;
- allocation of storage space and facilities for handling equipment. The need was demonstrated in the trial reported by Harrison [86];

7.2 Evacuation

In the case of evacuation of Australian or friendly nationals, accommodation rules will be relaxed if the severity of the situation requires it.

The implications for an evacuation vessel are:

- radio and or television transmitter capability to broadcast evacuation information to people affected if local facilities are damaged or outside control or influence;
- good communication links with service, police and /or embassy staff;
- ability to defend a vessel whilst in port, with the level dictated by circumstances;
- ability to feed, treat and accommodate evacuees;
- suitable landing craft for transportation of personnel and vehicles if port berthing is unavailable;

- reverse osmosis or ion tower water purification system replacing evaporative systems that cannot satisfactorily remove pollution[17]. The reverse osmosis is used as the benchmark by the US Defense Department but the further developments are expected in ion tower technology.

7.3 Peace Keeping and Operations Other Than War

Vessels used in peace keeping operations will need similar capabilities as vessels entering a war zone. However operations other than war such as disaster relief or evacuation may require the capability to treat large numbers of dehydrated and hungry people in addition to treating injured. Operations other than war may also include good will visits to remote areas, where general community care as well specialist services may be provided, for example, the US Defense department has a mobile breast care centre [82].

The implications for operations other than war are:

- medical facilities must be flexible and modular to tailor for different operational needs;
- onboard desalination facility.

8. Logistical Requirements

Recent research in the USN has revealed that *"47 % of the USN active duty enlisted force are assigned to maintenance (logistics) functions"* [14]. A similar percentage would be expected for the RAN. It can be readily seen that even a small increase in logistical efficiency would make a significant contribution to savings and/or redirection of personnel to the 'sharp end' of the services. The future logistical operations of the RAN and other services will see the introduction of more COTS systems and practices that have proven themselves in the commercial world. Information technology and communications will be essential elements and logistics will require the same high priority as operations and intelligence traffic [14].

A vast amount of the future technical developments listed below was obtained from Technology for the United States Navy and Marine Corps, 2000-2035 [14]. Although the time span extends to 2035 much of the technology listed exists today. The reader is directed to this reference for detail.

8.1 Repair and Maintenance

To facilitate efficient, minimal and remote area repair and maintenance, the future will see a move to the following type of technology:

[17] Some coasts have polluted water extending 50 kms or more from the shore making evaporative water purification useless [83].

- digitised maintenance manuals with intelligent agents to aid in troubleshooting faults[18];
- maintenance manuals will be specific to the model and make of the equipment (not just the generic class) and the latest information on repairs and troubleshooting hints will be available off the local network via the internet;
- systems will incorporate internal fault finding checking with the ability for remote monitoring;
- maintenance personnel will carry a portable readout device able to provide hands free information via a small head mounted display. It will also be able to be linked to the equipment and diagnose faults and order parts directly via a communication link;
- most equipment will be condition monitored thereby anticipating failure[19] and enabling parts to be ordered and replaced before the equipment fails;
- electronic and electric motor systems replacing mechanical and hydraulic systems, reducing maintenance and requirements for oil and lubrication.

8.2 Supportability

Support of the fleet and other forces will have significant impact on sea transport and the replenishment-at-sea capability of afloat support. The main thrust will be to increase efficiency by supplying the right item to the end user with minimal handling. Some of the technologies and processes that might achieve that are:

- digitised information enabling shared information of where inventories are located and current shelf numbers;
- intelligent decision aids to load inventories enabling efficient access to items. This will mean a move away from being volume efficient to packing what will be required in a way it can be obtained easily when required. This may also mean a move away from pallets to containers which have opening sides to provide ready access;
- databases and packing decision aids that enable requested items to be packed in a way so that when transferred to the requisitioning vessel all supply items are packed to suit the storage facilities available on that vessel[20]. Subsequently, there is no double handling;
- item identification systems to track and record locations eg. electronic tag and barcode technology linked to a logistical system;
- information technology to integrate the supportability of the fleet;

[18] Tests at the US Air Forces Armstrong Laboratory has shown that using an integrated maintenance information system, a general technician could perform almost as well as a specialist technician and could exceed a specialist technician when he or she were using the old paper manual approach to maintenance and repair [14].
[19] Failure would be anticipated from monitoring factors such as heating, vibration, noise, stress, strain, pressure, known lifetime, performance, etc.
[20] This would mean area would have to be available on a RAS vessel to enable this packing.

- automated reloading of vertical launch systems whilst at sea up to sea state 3. Current techniques are difficult, dangerous and slow (~3.5 missiles/hour);
- automated refuelling of vessels at sea would speed the refuelling process and reduce required manpower significantly. This could possibly be achieved by an articulated arm that targets itself to the side of the other vessel irrespective of relative motions between the tanker and the other vessel;
- stabilised crane technology that would enable supply items to be transferred safely between ships in rough seas.

Future requirements for logistic support will require mobility and the supply of water and fuel will always be challenging. Future sea transport and tanker designs may incorporate their own wet dock with high speed craft that would enable fast transfer of water, oil and other supplies to any position ashore.

8.3 Minimum Manning

One of the developments in ship design is the move to minimum manning levels. Minimum manning will be achieved through automation, multi-skilling and cultural and procedural changes. The outcome is to achieve a more efficient navy with commensurate cost reductions in construction, training and other support costs.

USS Yorktown of the USN has been established as the SMART Ship project [87] where ideas for minimum manning are trialed and assessed with an aim of reducing manning levels onboard this operational vessel. Some of the initiatives being trialed are:

- preventative maintenance systems replaced with a reliability centred maintenance philosophy. Estimated 30% reduction in man-hours;
- reduction in corrosion by the use of high tech processes aimed at specific trouble spots;
- computerisation of administrative records;
- centralised galley operation with the introduction of modern equipment;
- reduction in laundry requirements by a shift to 'all-hands' in overalls;
- a ready lifeboat requiring only 2-5 men to launch compared with 20-25;
- automated electronic safety Tag Out system for personnel;
- shifting to cashless post office, ship's shop and vending machines.

8.4 Amphibious Lodgement or Assault

The Australian Army generally expects an amphibious assault to be unopposed or to be only lightly opposed. Nevertheless, the assault force should be prepared. The threat of attack can be minimised by laying off shore beyond the horizon to reduce targeting. However this has implications on rapid movement of support material and personnel to shore.

8.4.1 Beach Landing

Beach landings may not always be possible due to the terrain but one technology being developed to overcome this is a foam based causeway between a vessel and the beach. This causeway is produced from a tough foam that expands 20-60 times its liquid volume. Tests in the US have demonstrated that it survived multiple tank passes, was damage resistant to fire and has some blast tolerance [14]. Another option being investigated by the USN is a portable dock. The dock would be towed to its required location and fixed to the sea floor by hydraulically driven posts.

Beach landings may also result in a vessel becoming stuck requiring the tide to rise before it can be re-floated. This problem may be alleviated by water jet propulsion systems where reversing the water flow direction and projecting it under the vessel could raise it without the need for the tide to rise.

9. Ship Design Features

Ship design is undergoing a revolution with the fast paced development of multiple hull designs and fast vessels. Future ship design will be based on the users requirements with a total system engineering approach to design, construction, test and evaluation, operation and ultimately disposal.

9.1 Hull Forms

Many hull forms are emerging, each with its own distinctive advantages and disadvantages. The following sections give a quick overview of hull designs that may impact on afloat support vessel design.

9.1.1 Multi-hull

Multi-hull vessels are characterised by a large breadth to length ratio compared to similar displacement monohulls. The principal advantages of multi-hulls are a greater main deck area for a given length, transverse stability and reduced wave making resistance allowing speeds in excess of 50 kts. However, in rough seas the cross deck structures of multi-hulls may slam into the waves subjecting the hull structure to high impact loading.

The technology for construction of conventional catamarans in the non-naval area is well established and these vessels could be used for military applications away from front line exposure.

9.1.1.1 Wave Piercing Catamaran

The emphasis toward improved sea keeping and ride quality has seen a move away from conventional catamaran forms to long slender hulls with round bilges. These hull forms reduce wash and wave making resulting in increased efficiency

In higher sea states, the structural cross piece between the demi-hulls will start to impact with the water causing slam loading to occur but minimising ploughing of the bow into and under the water. As a result, the sea speed of these vessels will not diminish appreciably as sea conditions deteriorate.

9.1.1.2 Trimaran

These vessels have low wave making resistance as a result of a long slender central hull although the skin friction is increased due to the increased surface area of the extra side hulls. A study on the R.V. Triton [88] claims that a reduction of 20% in hull resistance can be achieved. Trimaran hull forms offer additional stability over monohulls improving their sea-keeping qualities. As with other conventional multi-hulls, noise generating equipment can be installed above the water line to reduce the acoustic signature. The main deck is much wider than a mono-hull which may offer wider layout and design possibilities for combat systems, helicopter locations or cargo size or configuration.

9.1.1.3 Small Waterplane Area Twin Hull (SWATH)

These twin hull vessels are distinguished from conventional catamarans by having most of their buoyant volume in submerged cylinders attached to the ship structure via thin lengthwise struts [89] (Figure 20). The hull of the vessel rides out of the water achieving similar advantages to the catamaran and trimaran hull forms. The wet area of the submerged cylinders is greater than a monohull of equivalent displacement giving rise to greater frictional drag but because the vessel rides out of the water, it produces less wave making drag. The advantages over monohulls of similar displacement is its relative insensitivity to wave action and minimal speed loss in severe conditions because of the small waterplane area (until cross deck slamming occurs).

SWATH ships have a large draught for their displacement and the draught is sensitive to changes in load. This is an important consideration for shallow water operation.

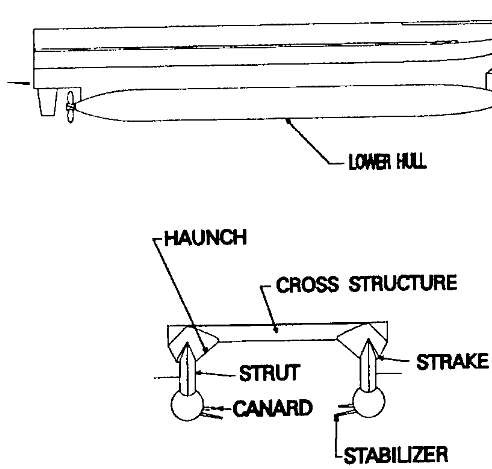


Figure 20. SWATH vessel hull form [89]

9.1.1.4 Surface Effect Ships (SES)

A catamaran style vessel that utilises an air cushion formed between its twin hulls and flexible bow and stern seals to reduce skin friction and wavemaking drag [90] (Figure 21). The SES is more efficient at high speeds than conventional craft requiring less power to attain high speeds. Commercially operated SES vessels are currently less than 200 tonnes but operate at speeds of up to 40 kts in calm water. Advantages of SESs are:

- sea keeping is generally better than most naval ships until the wave height is sufficient to cause venting beneath the side hulls;
- the hull shape is rectangular in plan form and cross section making efficient use of internal compartments;
- reduced draught in cushion mode;
- given a suitable propulsion system an SES can be beached;
- reduced underwater noise signature as propulsion systems are above the waterline;
- less susceptible to mine explosions than conventional displacement ships [91].

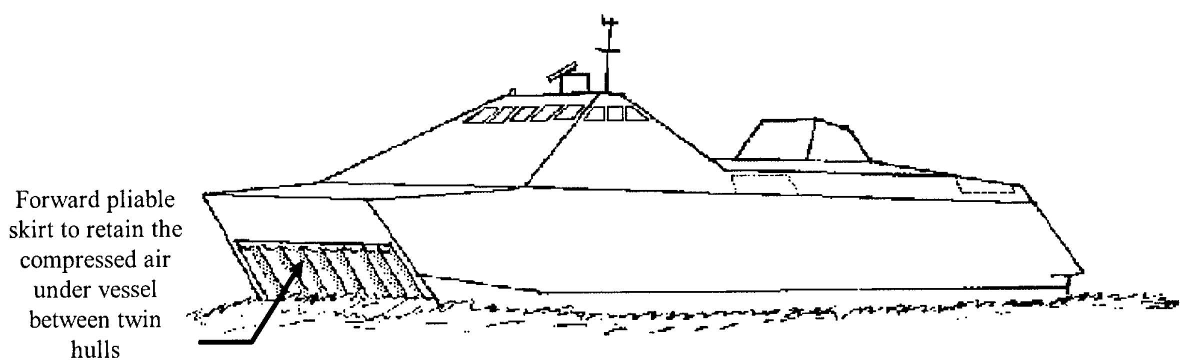


Figure 21. Experimental Swedish surface effect ship (SES), Smyge [90]

9.1.2 Mono Hulls

9.1.2.1 Planing Hulls

Driven beyond its displacement speed a planing hull will develop hydrodynamic lift. The hull rises out of the water as the speed increases leaving less hull area immersed in the water improving efficiency by reducing frictional drag.

9.1.2.2 Hydrofoils

Hydrofoils use the concept of dynamic lift using wing like surfaces attached to the hull providing lift to the vessel when sufficient speed is achieved. Lifting the vessel out of the water reduces both frictional and wave making resistance allowing speeds in excess of 60 kts to be achieved. The vessel's hull is lifted clear of the waves providing stability.

The hydrofoil drive train is complex and difficult to maintain and high power is needed to lift the vessel out of the water to achieve the benefits of the dynamic lift. When the vessel's hull is in the water, high frictional and wave making resistance must be overcome.

9.1.2.3 Wave Piercing Monohulls

These vessels come under the heading of high speed sea transport (>30 kts) with good sea keeping qualities in a wide range of sea states. The main feature of these vessels is the wave piercing bulbous bow which produces low wave making resistance and reduces pitch motions in head seas compared to similar displacement monohulls.

9.1.2.4 Deep Vee Hulls

The deep Vee hull (Figure 22) has a sharp water entry resulting in a smoother ride in rough water [35]. The deep Vee hull is narrow resulting in lower wave making resistance compared with conventional round bilge design. Frictional resistance is comparable. This design is not suitable for beached type landings .

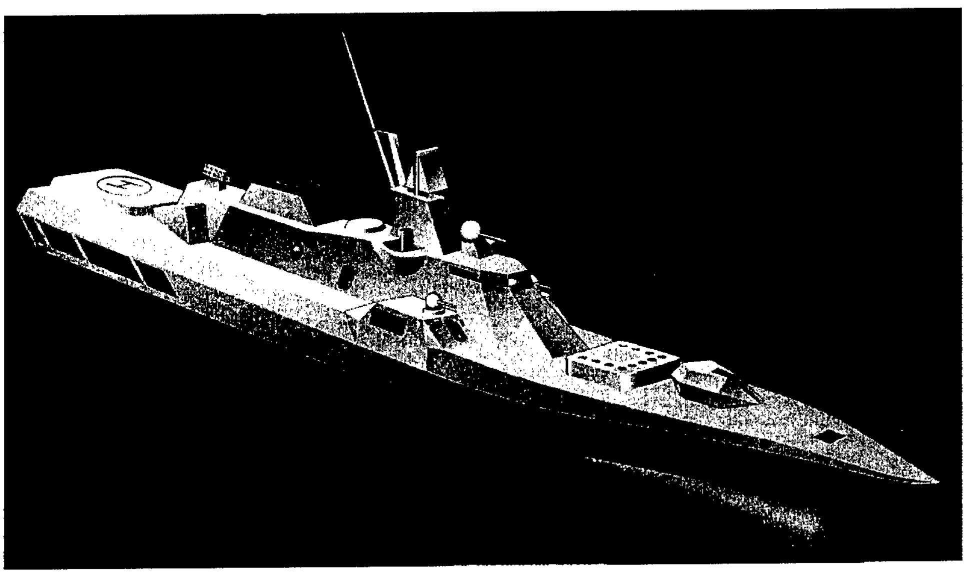


Figure 22. Conceptual deep Vee 55 kt surface combatant [35]

9.2 Civilian Classification Society Rules

Merchant classification society rules have been introduced [92] for naval vessels which will have an effect on ship design and construction methods. The primary reason for their introduction is to utilise commercial solutions for naval problems because of efficiency benefits and overall lower costs.

Classification society rules also ensure that naval ships comply with the International Maritime Organisation conventions on safety and pollution, requirements from which that they are currently exempt.

9.3 Flow Control

The external control of fluid flow along the hull of a vessel has the potential to reduce wake and acoustic signatures as well as improve efficiency by reducing hydrodynamic drag. Flow may be controlled by passive or active measures.

9.3.1 Passive Flow Control

Passive flow control is influenced by hull shape, surface treatment and appendages and these measures include:

- an integrated hull and propulsion system design;
- strakes and riblets on the hull surface to minimise boundary layer drag;
- smooth surface finish with 10 micron or less perturbations;
- anti-fouling coatings that reduce marine growth, improving hydrodynamic performance as well as reducing the associated wake and acoustic signatures.

9.3.2 Active Flow Control

This form of flow control requires the expenditure of energy to influence hydrodynamic flow. To be economically effective, the energy expended to reduce drag must be less than the energy saved due to the reduced drag. Some of the technologies to reduce hull drag through turbulent flow control are [14]:

- electromagnetic turbulence control (EMTC) [93];
- micro air bubbles or special polymer fluids expelled through small hull orifices;
- large eddy break-up devices;
- vortex control devices and convex surfaces.

9.4 COTS Equipment

The benefits of COTS equipment are twofold; (a) considerable cost benefit as development costs are minimal and (b) the latest systems/software can be installed as the technology comes on stream without the need for militarisation. This is particularly relevant to computer hardware and software.

One area in which a great deal of COTS equipment may be used is in integrated ship bridges [94] (Figure 23). These systems integrate:

- navigation displays and electronic charting;
- conning information display;
- auto pilot to keep vessel on pre-planned route including turns and also including compulsory safety functions;
- ergonomic workstations;

- horizontal information sharing: computers sharing information via a local network to provide a high level of redundancy for the whole system;
- data logging, e.g. speed, direction, GPS position, etc.;
- shallow water and collision alarms;
- engine control and monitoring;
- communications;
- ship management functions.

However, although the systems have high reliability, one area for development in integrated bridges is more detail to the man-machine interface and the use of intelligent software decision aids.

Figure 23. A modern integrated bridge system [94]

9.5 Modular Design

Modular design has two aspects: design and manufacture and, the ability of the design to be modified to suit different operational requirements.

9.5.1 Modular Design for Construction

Modular design enables flexibility in upgrading or installing new systems over the life of a naval vessel. The modular design technique allows systems such as weapons systems to be designed as modules which can be rapidly exchanged at refit. The ship is designed to accept modular systems resulting in a reduction in refit time and cost

9.5.2 Modular Design for Operations

Modular design enable reconfiguration of a vessel to a different capability by using modular weapon system packs, e.g. a naval gun replaced with a VLS. Traditionally this has been difficult due to the different types of connections needed for different weapon systems and different sensors. The development of the CLIDS network overcomes the problem as the nodes can be reconfigured by software to accommodate different systems.

One example of a modular naval vessels is provided by the Royal Danish Navy [41]. It has developed the Standard Flex 300 design (Figure 24) where containerised weapons systems and sensors can be altered to suit a requirement.

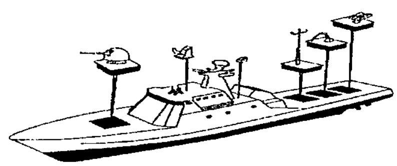


Figure 24. The Danish Navy Standard Flex 300 design. [14]

The Royal Danish Navy are currently planning to replace 17 of their front-line surface combatants with just six multi-role vessels. One modular system that is employed is a containerised vertical launch Sea Sparrow system [41] (Figure 25).

Figure 25. Containerised vertical launch system used by the Royal Danish Navy [41]

9.6 Ergonomics

Ergonomics will play a significant role in areas that include:

- troop comfort to ensure troops arrive fit and healthy and not seasick;
- improved computer interactive training and simulation for troops whilst on board;
- weapons and kit[21], requiring appropriate design of berths and kit storage;
- strategic location of troops on the vessel such that they are not far from ingress, egress and emergency stations;
- the use of queuing theory to ensure that troop loading and unloading is performed as quickly and efficiently as possible. This has implications on the storage of weapons in berths rather that armories; corridors and stairways being wide enough to allow 2 soldiers with full kit to pass, number and size of landing craft, helicopters, etc.
- the use of colour coded recessed lights in the deck to guide soldiers to their stations (similar to technology used in modern aircraft). It would also aid in smoke filled conditions;
- the use of modern design and technology commercially used in fast food establishments to speed serving and feeding troops.

9.7 Power Sources

For the immediate future, Naval propulsion will rely heavily on diesel fuel, with different fuels for aviation. However there is pressure to move to a single fuel to simplify logistics. The primary power source of naval vessels will move away from diesel engines to turbines coupled to electric generators as naval propulsion technology moves toward electric propulsion. One technology fast developing is the direct conversion of fuel to electric power by means of fuel cells.

9.7.1 Fuel Cell Technology

Fuel cells could be used to provide electrical power for ship propulsion. Fuel cells convert chemical energy into electrical energy without combustion resulting in lower acoustic and heat (IR) signatures and combustion process emissions. The fuel cell has no moving parts resulting in no wear or mechanical stresses, reduced through life maintenance costs and a projected long service life. Fuel cell technology is to be used for propulsion power in the new German U212 submarine [95] and is being tested in a surface vessel by the USN [96].

[21] For example, troops are more likely to carry individual communicators, GPS and computer systems that may require specialise storage with battery charging.

9.8 Propulsion Methods

9.8.1 Submerged Propellers

Partially submerged surface piercing propellers are currently used on high speed craft (30-70 knots) below 100 tonne displacement [97]. The propeller extends directly from the transom reducing appendage drag and is also useful for shallow draught vessels. The system can cause hull vibrations and noise as the propeller blades are operating only part of their revolution in water.

9.8.2 Supercavitating Propellers

These propellers are designed to promote cavitation in the blade wake rather than the bubbles collapsing on the blade. This enables a higher propeller speed producing more thrust. The propeller design is efficient and suitable for high speed craft but has an increased noise signature due to the cavitation collapse.

9.8.3 Vertical Axis Propellers

Vertical axis propellers will produce thrust in any direction through a change of blade pitch and as such produces good manoeuvring properties. The propeller design is not as efficient as conventional propellers and is not suited to high speed craft.

9.8.4 Water Jet

Water jets will provide increased propulsion efficiency for vessels with speeds in the range of 25-40 knots. This is because the system is not limited by the onset of cavitation. Water jets also produce less vibration thereby reducing the noise signature. The outlet nozzles can be directed, removing the need for a rudder and the absence of prop shaft appendages also increases efficiency. Water jets are located near the surface allowing a vessel to have a shallow draught.

9.9 Dynamic Positioning

One slow component of any amphibious support operation is the coupling of landing craft with the support vessel ramp or tying up along side. Part of the difficulty is the sea state and the potential of the vessel moving due to wind and sea currents or tides. Technology known as dynamic positioning allows a vessel to maintain position when subject to external forces. Dynamic positioning has usually been limited to offshore support vessels, research ships, semi-submersible rigs and other specialist ships. It is now being used by other vessels such as large tankers and cruise liners [98].

Using dynamic positioning on afloat support vessels, approaching landing craft will be able to moor quickly due to the stable platform provided to them. Dynamic positioning may also make technology for automatic mooring of landing craft more easily obtainable. The technology may also be extended to automatic mooring of the afloat

support vessel itself. The use of bow and stern thrusters may also offer some benefits in freeing an amphibious vessel from a beach.

9.10 Electric Propulsion

Electric drive is an alternative to the conventional engine/gearbox system. A motor generator driven by the main (conventional) engine provides power to electric motors attached directly to the propeller shaft, by-passing the gearbox which contributes appreciably to the acoustic signature.

Technologies contributing to this electric propulsion development are:

- advanced permanent magnets;
- high power, high performance solid state electronics making high power conversion technology economical;
- low temperature super conductors.

9.11 Integrated Power Systems

Integration of power systems will provide cost savings in fuel consumption and will decrease maintenance. Estimates by the US NAVSEA are 15-19% overall savings in fuel with the use of integrated power systems [99]. By use of the CLIDCS intelligent network, see Section 6.3.3, only those systems required will be running and running at the highest system efficiency possible. For example, instead of two pumps running at low speed a single pump will be running at a higher and more efficient speed.

10. Environmental Aspects

The environmental conditions must be considered in any choice of a naval vessel for Afloat Support activities. As a system, an inability to interact with the environment will result in a vessel that cannot meet its requirements.

10.1 Sea Environment

Afloat support vessels, as with any other naval vessel, will operate in hostile sea conditions. Any new vessel design must take into account these conditions and be able to operate effectively within them. Consequently, knowledge of those conditions is essential when considering a ship design.

10.1.1 Wave Heights

Sea state codes provide a measure of wave severity 'or state-of-the-sea' and the World Meteorlogical Organisation (WMO) sea state code is described in Table 5 [100]. For the WMO code, each sea state number corresponds to a significant wave height range, however the wave period is not considered, resulting in the sea state code being a limited description of wave severity.

Table 5. World Meteorlogical Organisation Sea State Code [100]

Sea state code	Significant Wave Height (m)		Description
	Range	Mean	
0	0	0.00	Calm (glassy)
1	0 - 0.1	0.05	Calm (rippled)
2	0.1 - 0.5	0.30	Smooth (wavelets)
3	0.5 - 1.25	0.875	Slight
4	1.25 - 2.5	1.875	Moderate
5	2.5 – 4.0	3.25	Rough
6	4.0 - 6.0	5.00	Very rough
7	6.0 – 9.0	7.50	High
8	9.0 – 14.0	11.5	Very high
9	>14.0		Phenomenal

Comprehensive wave height data are available for regions around the world from Young and Holland [101] and Hogben *et al* [102] but discrepancies exist between these sources. For the northern and northwest coastal area of Australia, the Young and Holland wave heights are less than that of Hogben *et al* and the discrepancies that exist between the various sources available should be appreciated.

10.1.2 Winds

Knowledge about prevailing winds is important particularly for amphibious landings because they generate waves and cause boats, landing craft and slung loads on cranes to swing. They have the potential to make loading and unloading from or between ships difficult. Wind interaction with opposing currents can also produce extreme sea conditions making coastal operations difficult for landings or lodgement.

The northern part of Australia also suffers from tropical cyclones where the sustained wind speeds can exceed 17 metres per second (>60kph).

Data bases on wind speed are also available from Young and Holland, and Hogben *et al* and the discrepancies in data from the different data bases that applied to wave heights also applies to wind speeds.

10.1.3 Ocean Currents

The marine research division of the CSIRO as part of the World Ocean Circulation Experiment has measured currents off North West Australia [103]. The CSIRO is also mapping ocean currents off the coast of Australia that will ultimately result in real time ocean current maps for the whole of the Australian Economic Exclusion Zone [104]. This information linked to navigational software could aid in plotting the fastest course between two points.

10.1.4 Sea Fouling

Sea fouling in the Northern waters of Australia is considered equal to the worst in the world. Without proper protection it will affect the operation of heat exchangers, propellers and water jets and increase hydrodynamic resistance.

10.1.5 Sea Temperature

The temperature of seawater has a number of implications in the design of an RAN vessel. Warm waters increase corrosion, require larger heat exchangers (e.g. for air-conditioning systems) and therefore larger pumps resulting in greater energy use greater effort in noise damping.

10.1.6 Ozone Depletion

Potential ozone depletion has implications for the RAN due to the increased ultra violet (UV) radiation:

- polymers, sealants, composites and elastomer materials currently used on vessels may not have the same reliability if exposed to increased amounts of UV radiation. Formulations may need to change to provide greater UV protection or materials replaced with alternatives;
- greater protection for personnel against UV skin damage.

10.1.7 Ice and Snow

Areas of icing conditions: In the southern hemisphere any area south of Latitude 60°S is considered to be an icing area where full icing accretion allowances should be applied in the design of a vessel [105]. This area encompasses the Australian Antarctic Territory. Note that in the Northern Hemisphere, areas of icing include the Korean Peninsular where the RAN has operated. Figure 26 shows the typical areas of sea icing in the world.

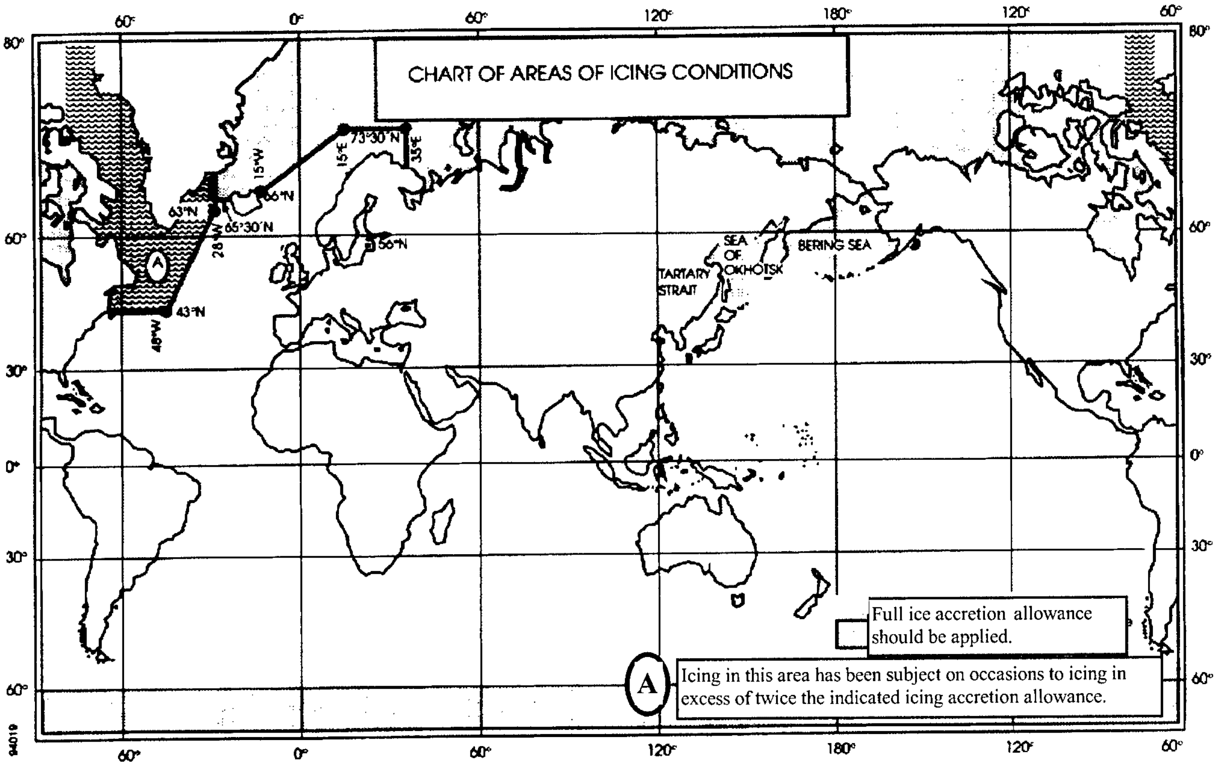


Figure 26 Chart of sea icing areas in the world [105]

10.2 Coastal Conditions

Coastal conditions will dictate the type and time of landings. Differences in tides, slope of the sea bed and the type of coastline will all have implications on amphibious operations and the type of vessels and support craft required.

10.2.1 Tides

Tides play a role in amphibious assault as the extent and period of tides provide defined windows of opportunity for an amphibious landings, LOTS, replenishment at sea near the coast and the unloading or loading of landing craft at sea or in ports. With amphibious lodgement or landing, large differences between the high and low water mark combined with a very low slope in the sea bottom can mean a difference of several kilometres between the dry shore line and the water mark [106]. In ports it could mean an inability to achieve roll-on-roll-off (RO-RO) capability or a reliance on port cranes.

Data on tidal information can be obtained from the Australian National Tidal Tables [107]. The data is presented as the difference between the Lowest Astronomical Tide (LAT) and the Highest Astronomical Tide (HAT). Neither of these will necessarily occur each year but they are the limits of normal astronomical conditions. Metrological conditions such as storms and varying barometric pressure can alter these values.

Barometric pressure seldom produces changes exceeding 300 millimetres but storm surges can account for further significant increases or decreases in tides.

Table 6 displays the extent of tides in for Standard Ports[22] in Northern Australia and New Guinea [107].

Table 6 Maximum tidal change between HAT and LAT in Standard Ports north of 25°S.

Locations	Maximum difference between HAT and LAT metres (location)
North Western Australia, North of 25S	10.9 (Yampi Sound)
Gulf of Carpentaria	4.7 (Karumba)
Cape York and coastline, North of 25S	6.6 (Mackay)
New Guinea and Islands in East	2.9 (Port Moresby)
Cocos Islands	1.2

10.2.2 Coastal and Tidal Currents

Tidal and coastal currents around Australia can be severe enough to affect the speed-of-advance of slow moving vessels such as the Landing Craft Heavy (LHD). This combination of affects can result in a negative speed-of-advance.

10.2.3 Sea Bed Slopes

Sea bed slopes in some parts of Australia are so low that tides can mean a difference of 30 kilometers between the high and low water mark. This terrain essentially excludes beach landings by ships.

10.2.4 Mangroves

Mangroves can provide an almost impenetrable barrier to beach landings and any subsequent effective movement of troops or equipment ashore by landing craft.

10.2.5 Rock and Mud

Rock provides difficulties for beach landings by placing undue stress on the hull of the vessel or making it difficult for landing craft. An amphibious vessel landing on mud can become stuck requiring a tug to be refloated.

10.2.6 Inland terrain

The inland terrain may not at first appear to have implications for afloat support but the environmental conditions can affect afloat support operations. Winds blowing offshore can carry dust that can affect aviation either by visibility or ingress of the dust

[22] Standard Ports are ports where tidal observations have been made over one or more years.

into motors. The dust may also affect radar, communications and sensors, particularly electro-optic sensors both on the vessel, landing craft or aircraft.

One other environmental condition often experienced in Northern Australian is smoke produced from inland bush fires. This can affect visibility sensors in a similar manner to dust. Smoke particles coating aerials may induce shorting.

Monsoonal rain in northern Australia will lead to inland flooding making land transport impossible. Increased river and large creek flows will influence currents and tides having implications on JLOTS and beach landings.

10.3 Temperature

High air temperature near the sea and land can induce refractive effects that can have implications for sensors, particularly optical sensors.

High air temperature and high solar radiation can also affect equipment that has been designed for cooler northern climatic regions, leading to problems with reliability.

10.4 Atmospheric Aspects

Atmospheric effects can have significant implications for operations and design of vessels. Propagation of electromagnetic radiation, e.g. radar, radio, lasers (rangefinders) can all be affected. Reliable operation of equipment (e.g. remote sensing) will be influenced by atmospheric factors, e.g. humidity, dust, smoke and haze.

11. Material Developments

The following sections discuss some recent developments in materials technology that could have implications in the design of vessels or systems for a future afloat support force.

11.1 Metals

Duplex stainless steels are replacing marine grade austenitic stainless steels, these materials have higher strength resulting in reduced sections thereby realising cost savings. They also have improved crevice and pitting resistance [108].

Current marine grade copper alloys may be replaced by a new range of copper/nickel/chromium alloys for valves, condenser tubes and cooling pipe systems [108].

11.2 Explosives and Associated Technologies

Incremental improvements in lowering the sensitivity of explosives to sympathetic explosion and heat tolerance are expected to occur. Future gains in explosive energy

density could make significant differences to naval ordnance. The Los Alamos Laboratory is conducting research into synthesised polymeric materials, e.g. polymeric nitrogen [109]. These materials offer the promise of twice the energy density of existing high explosives doubling the explosive payload of naval ordnance.

Promising research is underway at Los Alamos and at the Lawrence Livermore National Laboratory on the tuning of fragmentation damage to 'achieve a kill while minimising collateral damage' [109].

Technology areas likely to see improvements [110] are:

- smart warhead and fuzes allowing the real-time tailoring of the explosion to suit the type of target to be sensed by the fuze;
- miniaturisation of fuzes using micro-electromechanical (MEM) technology;
- penetrator technology improvements due to new high density alloys;
- the use of high density metal powder in explosives to enhance heavy penetrating bombs for defeating hard targets.

11.3 Fuels

There are two future developments that may have implications for afloat support. The first is a move to a single fuel for the services. The US is moving this way and during the Gulf war JET A-1 was used successfully by several US Air Force, Marine Corps and Army units [111]. It was used for aircraft, ground vehicles, weapon systems and equipment, and reported that the use of a single fuel increased tactical flexibility, simplified logistics and maximised fuel transport equipment.

Another development is the stable storage of hydrogen within carbon nanotubes [112]. The energy density of the stored hydrogen is superior to that of diesel or any other liquid fuel currently in use[23] and this energy storage capacity would allow a vessel to travel a greater distance than it currently travels on current fuel load, with the added benefit of zero emissions.

11.4 Signature Materials

The range of materials used for signature reduction is broad due to the nature of the different types of signatures. Some of the future developments [113] include:

- broad spectrum materials involving complex laminates with minimum polymer and metallic layers;
- chameleon layers for visible camouflage;
- smart (frequency tunable) materials that may absorb or transmit radio frequency energy as desired.

[23] Estimates of the storage capacity state a 50% efficient electric car could travel 5,000 km on a "fuel tank" approximately half the normal size of a traditional car!

To achieve stealth in the HF radar range, the outer skin of a vessel may be up to 20 cm thick. This outer skin thickness may also aid buoyancy, damage and shock mitigation.

11.5 Polymers and Fibre Composite Materials.

There will be continuing incremental improvements in polymers. One new development is polymer-clay nanocomposites that are showing increases of 40% in tensile strength, 126% in flexural modulus and 85°C in heat distortion temperature [114]. This material has high intrinsic dampening and is suitable for naval sonar domes [115].

11.6 Sensors

Sensor development appears to be growing at an exponential rate in miniaturisation, sensitivity and applications. Such sensors will be linked to integrated monitoring systems providing performance data on all forms of equipment. Recent developments include:

- miniature sensors to detect lethal airborne or water borne molecules [116];
- a fibre optic sensor that is able to detect chloride. It is able to detect predetermined level of chloride resulting from salt encroachment into structures and consequently measure the level of damage [116].

11.7 Paint

A recent development in protective paint technology has been announced that allows the detection of metal corrosion without paint stripping. A special paint additive will fluoresce under IR illumination if corrosion has occurred under the paint [117].

11.8 Ceramics

Developments in ceramics include:

- economically produced lightweight, machinable, thermally conductive composites of alumina-reinforced aluminium;
- fire retardant ceramic slurry coating for fibre glass. The material approaches a perfect black body reflecting heat. It would have applications in heating and cooling systems [114];
- Ceramic ball bearings yielding a 2-4 times increase in lifetime of bearings.

11.9 Thermal Insulation

A recent development is aerogel material technology. Aerogels are ultra light[24] with very high thermal resistivities and are structurally strong. They exhibit thermal R-values exceeding polyurethane and fibreglass by 2 to 10 times thereby enabling savings in volume and mass for thermal insulation [118].

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[24] Due to the matrix like structure of aerogels they can have a density which is less than air.

11.10 Nano Materials

Nano particles will have implications for incremental improvements in existing materials due to the microstructure that nano particle manufacture allows. One interesting application of nano particles is the improvement of thermal conductivity. Argonne National Laboratory has improved the thermal conductivity of heat transfer fluids that can mean smaller heat exchangers, pumps and better thermal control [119]. The addition of 1% volume of nano particle copper oxide improved the thermal conductivity of water by 15% with the nano particles remaining in suspension.

Nanometre sized metal fuels, e.g. aluminium, incorporated in explosives may produce enhanced blast effects [110].

11.11 Magnets

Rare earth magnets have made a big contribution to the development of small powerful electric motors and the cost of these magnets is decreasing with greater market penetration. Magnet development that is nearing commercial reality is high power plastic magnets. The Stevens Institute of Technology [120] has developed high permeability plastic magnets by filling plastic with magnetic powders. Relative permeability's 20-50 times higher than traditional plastic magnets have been achieved, which allows the moulding of highly shaped geometries that could improve the performance and applications of electric motors.

11.12 Shape Memory Alloys

These materials are used increasingly within the commercial world to replace electric motors and associated gears and levers and more complicated sensors. Their use will increase reliability, simplify maintenance and repair. The US Air Force is investigating uses for these materials in vibration isolation, structural control, and deployment and separation functions [121].

12. The International Legal Environment

In an increasingly litigious world with an ever increasing list of regulations being drafted and enacted, it is very important that the legal environment be considered in any future ship design.

This section provides an overview of national and international laws within the maritime area and the implications these laws will have on future ship designs for the RAN within the afloat support force.

The legal responsibilities of the RAN ultimately resides with the Australian Government. These responsibilities cover *'public international laws that define the rights and obligations of nation states vis a vis each other and the world community at large'* [122]. They also cover national laws when visiting other countries and the relevant local

regulations of ports that RAN vessels visit. There are also many Commonwealth and State Laws and Acts that are not binding to the Navy due to the nature of its business. Nevertheless, *'The RAN agrees to comply with all anti-pollution laws applicable to Australian and foreign ports which it visits, as far as is reasonable and practicable and where operational commitments permit'* as stated by Captain Miers *et al* for the RAN and the Australian Department of Defence (Navy) [123]. The report by Miers *et al* also gives a very clear picture of the RANs current endeavours to tackle the problem of pollution at sea. However, the future holds an increasing international demand for 'clean' ships as future operating options of the RAN diminish.

The international agency responsible for the formation of international conventions, codes and other instruments covering ship construction, equipment and operation is a specialised agency within the United Nations; the International Maritime Organisation (IMO). This organisation has a membership of 158 countries as of December 31, 2000. In consultation with and with agreement of its member states, the IMO updates and establishes international conventions within the maritime area. Some of the more important conventions are: Safety Of Lives At Sea (SOLAS) and International Prevention of Pollution from Ships (commonly known as MARPOL 73/78 or MARPOL). Legally, IMO conventions only apply to merchant shipping, however the RAN is committed to meet environmental conventions described in its Environmental Policy Manual [124].

12.1 Polluting Emissions

The most important legislation covering discharge at sea is encompassed within the MARPOL convention. This convention contains the following annexes:

- **I** Oil;
- **II** Noxious liquids in bulk;
- **III** Harmful packages in packaged form;
- **IV** Sewage;
- **V** Garbage;
- **VI** Air pollution.

The passing of the 'Protection of the Sea (Prevention of Pollution from Ships) Act' in 1983 has allowed Australia to implement Annexes **I, II, III, IV** and **V** of MARPOL. Accordingly, all Australian registered merchant ships must meet these conventions throughout the world.

In general terms, the MARPOL regulations specify the allowable amounts of material, in what form and where discharge of the material may occur. It is generally regarded that environmental laws will become tougher [125]. Accordingly, legislation is moving toward the imposition of zero sea discharge commensurate with the requisite containment of any pollutant within the vessel for disposal at shore. In fact, a North Atlantic Treaty Organisation (NATO) scientific study group (SG/50) has a design objective for a zero discharge vessel, or failing that, an outflow that is benign [126]. The

aim is to have a vessel capable of operating world wide without constraints due to current or future local or national environmental laws.

12.1.1 Oil or Oily Mixtures

Under current MARPOL regulations, oily mixture discharge from machinery spaces may not exceed levels of 15 parts per million. Consequently, the use of oil separators and the associated storage of collected oil is required. Expected future trends will see a tightening of this regulation towards zero or near zero emission of oil or oily mixtures. This expected requirement will have particular implications on refuelling operations at sea besides normal tanker operation. It also has implications on the ports visited because the ports will need to provide appropriate waste disposal facilities. It is likely that this requirement will place some restrictions on peacetime voyages depending on the availability and suitability of port disposal facilities. It is quite possible that some nations, e.g. island nations, may even refuse any port disposal due to limited facilities on land. As such facilities incur operating expenses, it is expected that countries with those facilities will ask the polluters to pay for their use [127] and the RAN will need to allow for such costs in visiting national and international ports.

12.1.2 Garbage

As is a signatory to the MARPOL 73/78 convention, all[25] Australian vessels are prohibited from dumping plastic waste and any garbage that floats (excluding paper, cardboard and food waste) anywhere at sea. The disposal of other waste (e.g. paper, cardboard and food) is allowed according to the location at sea and whether the material has been comminuted or ground. The rules for discharge at sea are described by Roseblade [128].

However, sea discharge legislation is also expected to become more stringent. Ships will need to incinerate garbage onboard (whilst also meeting air pollution standards and minimising IR signature) or compress and store it onboard for disposal at port. Storage onboard is seen as the preferred option as it is relatively simple and does not produce an IR or disposal signature. However the choice of incineration[26] or compaction is also related to the type of vessel [128]. Nevertheless, it will mean the installation of the requisite equipment together with a temporary or total storage facility on board. The garbage facility will also need to meet appropriate occupational health and safety (OH&S) standards.

It is considered that the technology to meet either incineration or compaction requirements exists today although it may require some modification to meet the full requirements of the RAN [128]. One aspect in future ship design which works in favour of garbage storage onboard is the move in western Navies to minimum

[25] All Australian shipping because the RAN has made a commitment to meet the requirements of the 1983 Protection of the Sea Act.
[26] Incineration of garbage also allows incineration of waste oil and possibly oily water. However, strict NO_X and SO_X emission regulations already being introduced may complicate the system design and cost.

manning of ships, thereby reducing the amount of garbage generated. However, the average garbage mass generated per person is not expected to decrease significantly.

Vessels currently require a garbage log of all waste disposal and any discrepancy with known levels of waste for the type of vessel could incur port detention and fines [127]. This log is known as the Garbage Record Book. A further restriction may also be the compulsory disposal of all waste before a ship leaves port [127]. This latter idea has the potential for ports to charge whatever fee the market will bear and conceivably some nations will attempt to exploit such charges. These latter two points are indicators to the future thinking on waste disposal

12.1.3 Sewage

Under current international laws, untreated sewage (also known as Blackwater) can be discharged from holding tanks in open waters (outside the 12 nautical mile limit) and the occurrence is increasing [129]. Studies within the Great Barrier Reef Marine Park (GBRMP), the North Sea and the Caribbean have conclusively demonstrated that such discharges are harmful to the sea eco-systems [129]. Subsequent Australian legislation limiting sewage discharge within the GBRMP (known within the RAN as the Great Barrier Reef (GBR) Region) has restricted RAN operations due to the type of sewage treatment equipment they carry [128,129]. Accordingly, the RAN has an ongoing action to meet and expand on the conditions of MARPOL which is detailed in Miers *et al* [123].

It is expected the future will inevitably hold tighter legislation concerning the disposal of sewage. Consequently, the requirements to hold and treat the sewage before discharge at sea whilst also controlling the release of undesirable chemicals (e.g. chlorine) will become more strict. Port facilities taking sewage discharge will become more commonplace but with commensurate charges based on a user pays philosophy. Procedures may become more complex if chemical treatment of the sewage is required before disposal.

12.1.4 Exhaust Gases

Annex **VI** of MARPOL 73/78 on the Prevention of Pollution from Ships introduced strict international controls on air pollution at sea. This convention means that merchant ships of the signatory nations are prohibited from releasing any ozone depleting substances and are required to control nitrogen oxides and sulphur oxides releases. These exhaust gas restrictions may require exhaust monitoring equipment for specific pollutants so that regulatory officials can be assured that the regulations are being met [130]. Table 7 lists the types of pollutants that are regulated under Annex **VI**. Table 7 also gives potential implications on ship design for the RAN.

Table 7. Pollutants to be regulated and the implications for ship design [130]

Halons	Used in portable and fixed fire extinguisher systems, they will be banned in new ships. Existing ships will not be affected but it is likely that within the next 10 years existing ships will have to meet Annex **VI** conventions.
Chlorofluorocarbons (CFCs) and other ozone depleting substances	Used in refrigeration systems and in some thermal insulation materials. These materials will be banned from all new installations onboard ships. Existing ship installations will not be affected at present (see comment above). Existing technology using hydrochlorofluorocarbons will currently be allowed until 1 January 2020.
Nitrogen Oxides (NO_X) (NOx is a potential killer aggravating lung disease and also leads to the generation of low-level ozone which has a similar effect [131])	It is intended that NO_X will only be regulated in new diesel engines. The IMO will review these limits at five year intervals and it may lead to a common limit for all engine types [132]. It is interesting to note that this is a difficult technical challenge for diesel engines and it may make steam propulsion more attractive if NO_X emissions cannot be controlled [130]. However, the nitrous oxides are also formed during combustion in petrol engines, gas turbines, boilers and rubbish incinerators. Therefore, regulations encompassing these forms of combustion cannot be ruled out have having significant engineering implications for future ships. These requirements would include selective catalytic reduction systems in the exhaust system of a ship and changes in engine operation, eg retarded injection [133]. However, legislation will require continuing development in this area. Exhaust monitoring equipment will be required for NO_X emissions.
Sulphur oxides (SO_X)	SO_X have been identified as the main cause of acid rain [134] and their emissions will be regulated in all ships. Exhaust monitoring equipment will be required.
Volatile Organic Compounds	These compounds are released during cargo operations involving petrol and crude oil. Implications to ships will cover the manner of operations and the protective measures in place.
Shipboard incinerator emissions	Regulations will cover emissions from shipboard incinerators. These will also have implications on the engineering and monitoring requirements required onboard.

Another major cause of air pollution from ships is the use of sub-standard fuel oil, e.g. high sulphur oil. Subsequently, MARPOL will stipulate the quality of oil supplied to ships [130]. This will have implications where RAN ships must refuel in foreign ports and may also require an easy onboard means of confirming the quality of oil purchased in such ports to ensure the MARPOL convention are not breached.

In the technical area of pollutant monitoring, it is believed that the technology exists having been developed for land monitoring purposes [130]. Future requirements will include marinisation of equipment and it will certainly decrease in size. It is almost

certain that such equipment will also be connected to a computer controlled engine combustion management system in the same way as exhaust sensors are linked in modern automotive engine management systems. Such systems will also need to record and report on the vessels pollution monitoring system to demonstrate compliance with the regulations to appropriate marine or port authorities.

Other implications for the RAN in addition to design and installation costs will be associated with staff training and supportability of the equipment. In addition, these aspects may be handled by contractors, raising liability issues if operational emissions do not meet MARPOL standards.

One emission not mentioned in the proposed MARPOL Annex **VI** is carbon particulate emissions. Diesel engines are the main source of carbon particulates that are less than ten micrometres in diameter. These particles are known as PM10s and have been linked to respiratory distress and deaths by the World Health Organisation (WHO) [135]. It is expected that world wide legislation on emission of these particulates will occur. Although the relationship between PM10s and respiratory problems is strongly denied by industry, the evidence is accepted by WHO and has led to statements: *'the health effects of particles represents the biggest change in air pollution toxicology in the last 20 years'* [135]. There will inevitably be legislation on land about PM10 particles due to research demonstrating the health hazards associated with them [131] and in all probability this legislation will move offshore like other air pollution legislation, e.g. Annex VI of MARPOL.

Implications for the RAN will be in the design of exhaust systems that will require filtering (e.g. electrostatic) and subsequent storage and disposal of the offending particulates.

12.1.5 Ballast Water

The discharge of ballast water from ships within Australia has been of considerable concern to Australian officials concerned with environmental protection. Ballast water taken on at ports can readily include plants, bacteria and animals that can survive inside ballast tanks [123]. The contaminated ballast water can be discharged in a home or international port possibly upsetting the local marine ecology with a non-indigenous species. Current guidelines on procedures to minimise risks from the introduction of unwanted marine organisms are detailed in the IMO Resolution A 868(20) [136].

Currently the RAN takes appropriate measures to minimise risk by ensuring only clean water is taken on board and ballast water exchanges only take place at distances of 50 nautical miles from the nearest land and the GBR region [123]. However, like other pollution aspects the legislation is expected to become tighter. Possible options could include treating the ballast water to ensure all ballast organisms are killed. Of a number of techniques discussed by Taylor [137] the use of waste heat to raise the temperature of the ballast water to a point that all organisms are killed appears to be a simple and cost effective method (this method also appeals as a means of reducing the

IR signal when stealth is required). Other methods will require extra room for machinery, etc. Whatever method is adopted, there will be some inherent cost for the RAN and associated data recording of the process for legislative purposes. Use of waste heat could be performed automatically by the ships control system.

Another implication for the RAN, particularly if a large ballast is involved, is the 'at sea' transfer of ballast. This has some safety implications in relation to the proper structural design of the ship so damage, e.g. broken ship back, is not incurred during the ballast exchange process [137].

12.1.6 Antifouling Coatings

Antifouling coatings save significant fuel and dry docking costs by allowing a ship to maintain a clean hull surface and the RAN currently uses Tributyltin (TBT) antifouling coatings on vessels over 40 metres in length[27]. These antifouling coatings release TBT biocide into the sea to prevent aquatic life attaching to ship hulls. Nevertheless, TBT biocides have been shown to be harmful to other sea life [138] and their use is regulated in the national waters of many countries including Australia, UK and SE Asia [139] and banned in Japan, Sweden and New Zealand [140]. The IMO is aiming to phase out and eventually prohibit the use of TBT coatings [140].

Environmentally friendlier biocide alternatives such as copper based coatings are available but are expensive compared with tin based coatings although the copper coatings are also under scrutiny and are restricted in the Baltic sea [141].

Non-polluting silicone coatings have been developed that rely on providing a smooth, low friction surface to which sea life have difficulty in attaching. These are called fouling release coatings, also known as low surface energy coatings. This technology is still developing, although commercial products (e.g. Intersleek®) are available and are being subjected to trials by the RAN and the USN [141]. However, these products are approximately ten times the cost of existing TBT coatings and are susceptible to abrasion damage and subsequent fouling when vessels are alongside in port [141] .

An implication may be the requirement to apply only non-polluting antifouling coatings to RAN vessels. This may mean increased antifouling application costs but life cycle costs may be lower due to the efficacy of the coatings to remain clean and reduce fuel costs. Associated with antifouling coatings will be increased in-water cleaning[28] that is currently performed manually by brushing or water spray. The future may see automatic cleaning by robotic machinery. In addition, such cleaning may also become mandatory[29] before a vessel leaves port to avoid the transfer of unwanted sea organisms to other sea eco-systems [141]. Consequently, the development of an

[27] The 40 m length was selected to exclude fuel lighters and harbour tugs from using TBT anti fouling coatings, however there are some exceptions: the hydrographic ships (<40m) have TBT coatings due to open ocean work while the landing craft heavy (LCH) (>40 m) do not, as they stay close to shore.

[28] In-water cleaning means mechanical cleaning of the hull of sea fouling without having to dry dock the vessel.

[29] This may also depend on the period of stay within the port and the local sea fouling conditions.

efficient robotic cleaning system may be necessary for vessels visiting overseas ports. An alternative is the development of an efficient fouling release coating that guarantees all sea fouling collected in port would be removed before the vessel left the local waters by the action of the ship travelling through the sea.

12.1.7 Health and Safety Issues

The RAN has comprehensive training in safety beginning at induction with courses on the OH&S Act, specific safety instructions relative to occupational training, e.g. gunnery, wire and harness use, etc, to specific supervisor and management OH&S courses given throughout the careers of staff [142].

The philosophy 'Duty of Care' that is mandatory in workplace legislation also applies to staff onboard RAN vessels during all operations. Accordingly, the RAN aims to apply all required safety features in its operations to protect staff and equipment. Duty of Care is seen as a comprehensive philosophy and is clearly specified in legislation. Consequently, it is expected that future OH&S legislation will be concerned with the conditions laid out in safe codes of practice. The implication for the RAN is a continuing need to be aware of recognised hazards and codes of practice in order to inform and train staff appropriately.

12.1.7.1 Chemical Hazards

Chemical hazards relating to air quality (e.g. generation of carcinogens from breakdown of organic fluids) and the potential generation of explosive and toxic atmospheres will receive priority due to the need to provide safe work environments. It is foreseen that in addition to recommended codes of practices, there will also be a requirement for automatic monitoring, logging, control and hazard warning of chemical hazards. This will be achieved by computerised systems connected to the ships control system. There may also be implications on the development of appropriate sensors.

12.1.7.2 Ergonomics

Currently there are codes of practice for computer workstations and the future will see more legislation and codes of practice in these and other work areas to minimise the generation of repetitive strain injuries. Proper ergonomic design also ensures that crew members on station remain alert and effective. Subsequently, there is a strong self interest for the RAN to install ergonomic designs in future ships to achieve the most effective operation of, and defence of, a vessel and its crew.

One area that may have implications for personnel is the use of virtual imaging headsets. They may be used to display 3-D information to radar or sonar operators. However, difficulties in prolonged use can induce sensory input conflicts between what the middle ear is sensing and what the eye is seeing. This can lead to reduced effectiveness[30].

[30] Royal Australian Airforce pilots using flight simulators that do not physically move (only image moves) are not allowed to fly for 24 hours due to physical effects arising from the sensory conflicts.

Ergonomics can also extend to the overall design of a vessel for the functions that it must provide. For example, attention must be paid to:

- width of corridors for fully equipped soldiers and any equipment that may need to travel down the corridor;
- location of accommodation facilities to minimise effects of sea sickness and related issues associated with vessel motion;
- location of accommodation and storage spaces for efficient and rapid ingress and egress to and from staging areas including emergency assembly areas. Consideration should be given to storing weapons and personal issue munitions with troops to minimise ingress and egress delays. Application of modern queuing theory would provide help here;
- appropriate storage in accommodation areas for weapons and facilities for recharging batteries associated with equipment of the future soldier;
- the application of modern fast food technology in kitchen and servery design;
- correctly designed chairs and tables to accommodate the modern soldier;
- unisex toilets.

12.2 Design issues

The following sections discuss potential legislative issues relating to the design of ships. It is not all encompassing but raises those subject areas that would appear to be significant design issues in any future RAN vessels concerned with afloat support.

12.2.1 Hull

The international legal requirements of double hulls for new tankers (MARPOL 73/78 Annex 1 Reg 13F) will affect any replacement of HMAS Westralia. Double hulling is still a controversial issue amongst commercial carriers and the proof that double hulls will provide a safer form of tanker transport is still being debated [143]. Nevertheless, new oil tankers now require double sides and double bottoms [144] and for a tanker the size of HMAS Westralia, a two metre spacing between the tank walls and the hull. Implications for the RAN are the increased cost (commensurate with a lower risk of spillage and associated clean-up and damage costs) and possibly increased life cycle costs due to increased maintenance of the double hull.

Double hull designs also raise a number of OH&S issues:

- the potential for collection of volatile or explosive gas mixtures within the hull cavity;
- maintenance and inspection of the hull involves proper venting and appropriate operating practices for enclosed spaces.

These issues will lead to the development of automatic monitoring and safe venting of the environment within the hull cavity and robotic inspection procedures and simple maintenance, e.g. painting.

A double hull design will also increase the survivability of the ship subject to shock and/or blast damage.

12.2.2 Electronic Chart

The introduction of modern electronic charting systems has simplified the navigators' job. The use of global positioning satellites (GPS) and the electronic chart (otherwise known as the Electronic Chart Display and Information System (ECDIS) enables a ships computer to guide a ship accurately on course with very little error in position.

Although GPS and ECDIS is not yet a legal requirement on new or existing ships, it is currently being considered under Chapter V of the SOLAS convention. The future will certainly see such a regulation although there are a number of legal issues, e.g. liability, regulatory issues re: navigation and pollution control, that need to be fully resolved [122]. It is envisaged that in the future a combination of GPS and ECDIS will not only provide navigational data but also advise/monitor on regulatory issues such as pollution control, pollution monitoring, port facilities and port regulatory requirements.

The implication for the RAN is that it will be obliged to adopt such equipment for operational reasons even though warships will probably be exempt from the regulations. On adoption, the RAN in all likelihood will add to the ECDIS database its own defence related data, eg coastal conditions for amphibious landing. In modifying the data, the RAN then opens itself to liability in the event of a navigational or pollution accident. Accordingly, it will need to keep accurate detailed records of all changes it introduces. In addition it will also have to have adequate means of back-up navigation systems in the event of a power loss.

12.2.3 High-speed Craft (Including Dynamically Supported Craft)

It is highly probable that future RAN ships will travel at much higher speeds than currently possible. Such ships will have mono or multi-hulls and may incorporate dynamic support systems in order to maintain their high speed performance. Such designs raise further implications for the RAN in design aspects and operational procedures.

In the area of safe design the IMO has updated the safety code for such vessels. In May 1994, the Maritime Safety Committee adopted the international Code of Safety for High-Speed Craft [105]. This was developed from the Code of Safety for dynamically supported craft. At the May 1994 SOLAS Conference on Safety Measures for High Speed Craft the HSC Code was made mandatory for all new high speed craft after 1 January 1996. Although the code is not mandatory for naval vessels, the RAN would be obliged to follow the safety measures because of the potential legal implications if it did not.

One safety aspect of operating high speed craft not mentioned in the Code of Safety for High-Speed Craft is the damage (and subsequent litigation) that can be caused by such vessels. In operation, high speed craft can create large waves in their wake. These waves can damage sensitive shore environments, flip people out of craft and capsize surrounding craft particularly as wave height increases in shallow waters near shorelines. In addition, damage to the sea bottom can result from the wake of powerful water jets or high speed propellers. Limitations on operating speeds near shore or shallow waters are probable due to this behaviour.

12.3 Port issues

The requirement for appropriate port facilities for the disposal of waste have already been raised. However, the Navy's own ports may have to meet the MARPOL conventions in the provision of adequate waste reception facilities. Such facilities may vary from the provision of a skip for garbage to specialised receptacles for Black and Greywater, oily water discharge, etc. Such facilities will need to be where the ship is docked and be available around the clock for a port required to operate 24 hours a day [127].

12.4 Communications

From February 1999, all merchant ships over 300 gross tonnage will have the Global Maritime Distress and Safety System (GMDSS). The technology is constantly developing and one of the latest systems (INMARSAT-E [145]) combines GPS with geostationary satellite technology giving quick and accurate location within 200 metres cf. 5 kilometres with current systems.

Implications for the RAN are the necessary staff training for the technology. There is also the potential for the detention of a ship in a foreign port if it does not have the GMDSS installed. A number of countries are currently enforcing detention for non-compliance [145].

13. Conclusion

The emergent technologies described this report may have an impact on future naval ship design and construction where the principal factor in ship design is the capability requirements. The capability requirements of ASF vessels are defined by lift capacity, loading and unloading needs, range, endurance and replenishment needs, and technology will determine how the capabilities will be achieved.

This report has described some of the technologies that may be incorporated into ship design for the next generation of the RAN's ASF vessels but has by no means exhausted all possible technologies or ideas which will continue to evolve.

14. Acknowledgments

The following people are gratefully thanked for their advice and comments.

Boyd, Stephen, Maritime Platforms Division, AMRL, Melbourne.	Advice on covert laser communication between vessels.
Cimpoeru, Dr. Stephen, Maritime Platforms Division, AMRL, Melbourne.	Advice on light weight armour developments for naval vessels.
Conley, Dr. Dan, Maritime Operations Division, AMRL Sydney.	Advice on afloat support operational studies and provision of maritime database.
Fletcher, Lynn, Maritime Platforms Division, AMRL, Melbourne.	Advice and comment on environmentally clean vessels for world Navies.
Jewsbury, Dr Peter, Maritime Platforms Division, AMRL, Melbourne.	Comments on potential future materials design for signature management.
Kennett, Dr. Stephen, Maritime Platforms Division, AMRL, Melbourne.	Advice and suggestions on fire fighting technologies.
Lewis, John, Maritime Platforms Division, AMRL, Melbourne.	Advice and comment on antifouling coatings and bioluminescence.
Moore, Brian, Maritime Platforms Division, AMRL, Melbourne.	Advice on new developments in stainless steels and copper alloys.
Power, Dr. Alan, Airframes and Engines Division, AMRL, Melbourne.	Fuel data.
Twomey, Lt. B, 1 Psych Unit, Gallipoli Barracks, Enoggera, Queensland.	Advice and comment on requirements of Psychological Operations associated with Royal Australian Navy operations.
Vrbancich, Dr. Julian, Maritime Operations Division, AMRL, Sydney.	Advice on the sources and countering of DC and AC electric fields.

15. Glossary

Ballast Water	Sea water, uncontaminated by fuel, from trimming or ship stability. Fuel contaminated ballast water is categorised under oily waste.
Discharge	Any release, however caused, from a ship or support craft, and includes any escape, disposal, spilling, leaking, pumping, emitting, emptying or ditching.
Garbage	All kinds of domestic (including food) and operational waste generated during the normal operation of the ship or support craft and likely to be disposed of continuously or periodically. Food waste includes items such as: fruit, vegetables, dairy and meat products.
Greywater	Drainage from galley basins and dishwashers, showers, laundry and hand basins, but not discharge from food macerators.
Plastic	Plastic items such as: packaging, bottles, containers, disposable eating utensils, cups, bags, sheeting, floats, fishing nets, rope strapping bands, also ship construction items such as fibreglass and laminated structures, piping, foam insulation, flooring, carpets, fabrics, paints, finishes adhesives, electrical and electronic components.
Sewage (Blackwater)	Drainage and other wastes from any form of heads, urinals, and Water Closet scuppers; drainage from medical facilities (sickbays, dispensaries and medical areas) via washbasins, drains and scuppers located in such premises.

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SPARES (5 copies)

Total number of copies: 58

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION DOCUMENT CONTROL DATA	1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)
Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force	Document (U) Title (U) Abstract (U)

4. AUTHOR(S)	5. CORPORATE AUTHOR
G.A. Clark and I.A. Burch	Aeronautical and Maritime Research Laboratory 506 Lorimer St Fishermans Bend Vic 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-GD-0288	AR-011-881	General Document	May 2001

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
510/207/1183	IND SM/MGTMEL	CMPD	86	144

13. URL on the World Wide Web	14. RELEASE AUTHORITY
http://www.dsto.defence.gov.au/corporate/reports/DSTO-GD-0288.pdf	Chief, Maritime Platforms Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, SALISBURY, SA 5108

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CASUAL ANNOUNCEMENT Yes

18. DEFTEST DESCRIPTORS

RAN ships, technological innovation, replenishment-at-sea, ship design, amphibious operations,

Free term: afloat support

19. ABSTRACT

Emergent technologies are the technologies that may impact on future Naval ship design and construction. The driving factor in ship design in this century will be the capability requirements and as these change, emergent technologies will be needed to meet these new requirements. These technologies will define areas such as construction methods, propulsion systems, construction materials, signature management, survivability, self-protection, command and control and among other aspects, the legal obligations associated with operating ships on blue water or in port.

This report describes the technologies that will drive ship design for the next generation of the Royal Australian Navy's Afloat Support Force (ASF) where afloat support can be categorised under the following tasks:-.

- replenishment-at-sea;
- sea transport;
- amphibious operations, and
- logistics over the shore.

The requirements of an afloat support force are specific because of the operations they perform. These requirements encompass military lift capacity, loading and unloading needs, range, endurance, replenishment needs and environmental considerations. New technologies will lift the capabilities of the next generation of ASF vessels by making them faster, more efficient and less vulnerable. Improvements in capability will also translate to broader operational requirements of the afloat support vessels resulting in a more effective force.